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INVESTMENT IN RESEARCH AND DEVELOPMENT

HEARINGS

BEFORE THE

JOINT ECONOMIC COMMITTEE
CONGRESS OF THE UNITED STATES

ONE HUNDREDTH CONGRESS

FIRST SESSION

DECEMBER 2 AND 11, 1987

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INVESTMENT IN RESEARCH AND DEVELOPMENT

WEDNESDAY, DECEMBER 2, 1987

Congress of the United States,
Joint Economic Committee,
Washington, DC.

The committee met, pursuant to notice, at 9:41 a.m., in room SD-628, Dirksen Senate Office Building, Hon. Paul S. Sarbanes (chairman of the committee) presiding.

Present: Senator Sarbanes and Representative Scheuer.

Also present: William Buechner, professional staff member.

OPENING STATEMENT OF SENATOR SARBANES, CHAIRMAN

Senator **Sarbanes**. The committee will come to order.

This morning the Joint Economic Committee holds the first of two hearings on the Federal role in the Nation's research and development program. These hearings on R&D are part of the committee's focus on an area of issues which we have labeled "prudent investment," as we seek to identify those areas of the economy in which prudent investment is critical to the Nation's future economic strength.

Today, and in a second hearing which will take place on the 11th of December, the committee will attempt to assess the strengths and weaknesses of Federal research and development programs, and the role of the Federal Government in facilitating research and development in the private sector.

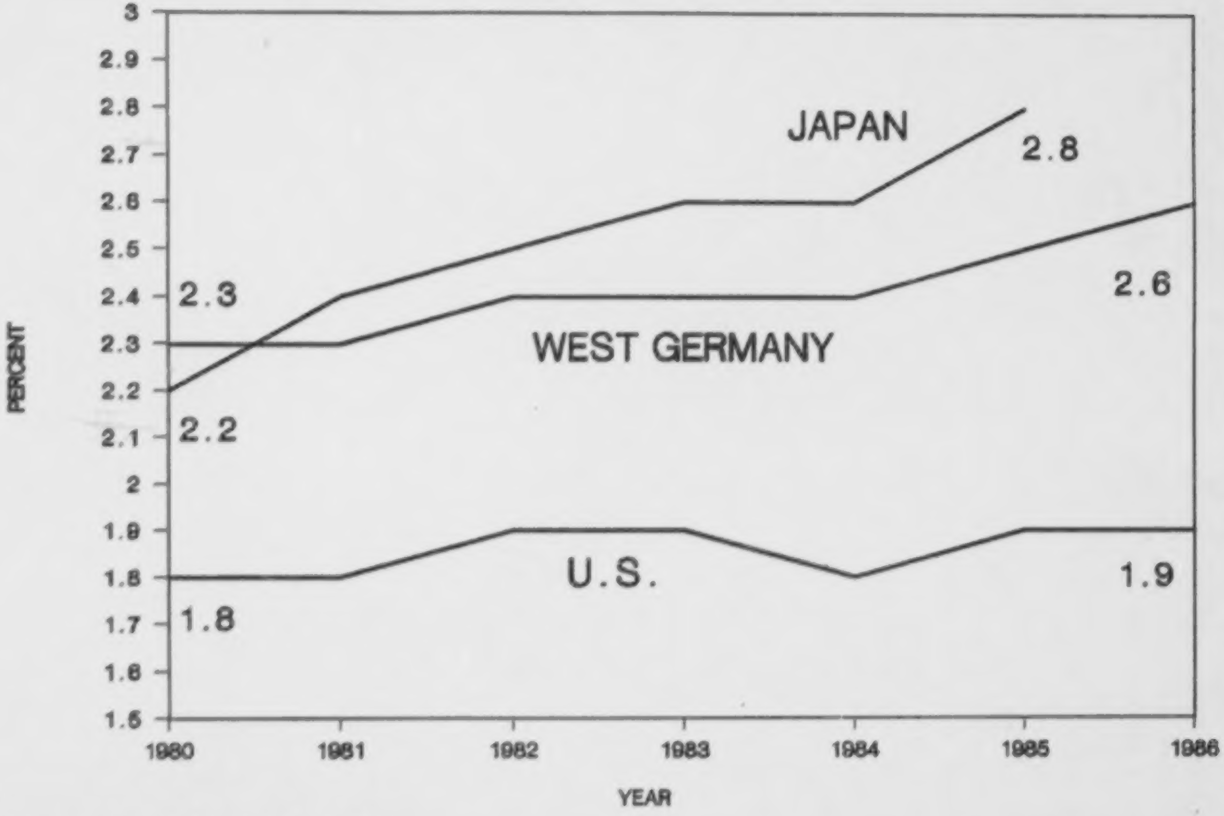
The committee's inquiry is prompted by concerns which were outlined earlier this year in the committee's 1987 annual report. The first is the dramatic shift in the focus of the Federal investment in research and development programs. From the mid-1960's until 1981, a rough apportionment of 50–50 was maintained between defense and nondefense programs. Today, that apportionment is approximately 70–30.

While Federal R&D expenditures increased almost 60 percent in the 5-year period 1981 to 1986, military R&D more than doubled, while nondefense R&D increased less than 6 percent.

The second dramatic shift is a failure of U.S. investment in nondefense research and development, measured as a percentage of GNP, to keep pace with comparable investments by West Germany and Japan. Since 1980, U.S. investment in nondefense R&D has remained constant, roughly 1.8 to 1.9 percent of GNP, while in contrast West Germany's investment increased 13 percent between 1980 and 1986 and Japan's investment increased more than 27 percent. Both of those countries are now investing between 2.6 and 2.8 percent in nondefense R&D. That is reflected in the chart here on the left, nondefense R&D as a percent of GNP, which shows the trend lines for Japan, West Germany, and the United States.

[The chart referred to follows:]

NONDEFENSE R&D AS A PERCENT OF GNP



Source: National Science Foundation

Senator **Sarbanes**. The widening gap has raised serious concerns about America's ability to compete successfully over the longer term in international markets. Notwithstanding a more realistic valuation of the dollar which has now come about, there is widespread agreement among economists that in basic research, which lays the foundation for new technologies and new products, the Federal Government may be better able than entities in the private sector to assume the costs and risks involved. And in fact, throughout the post-World War II era, the Federal Government has played a pivotal role in this area.

There are also important questions to be considered with respect to the relationship to Federal programs and research and development efforts in the private sector, where R&D expenditures have increased more than 250 percent since 1960.

In focusing today on trends in Federal research and development policies and expenditures, and on the policies and practices of our major trading partners, the committee is fortunate to have four very distinguished witnesses. We will hear first from Mr. Erich Bloch, Director of the National Science Foundation. Following Mr. Bloch, we will hear from Mr. Albert Teich, head of the office for public sector programs of the American Association for the Advancement of Science.

We will then turn to a discussion of the economics of research and development with a panel consisting of Professor Edwin Mansfield, University of Pennsylvania, and Professor Nathan Rosenberg, of Stanford University.

Senator D'Amato has an opening statement which will be included in the record, and he is hopeful that he will be able to make the hearing later in the morning.

[The written opening statement of Senator D'Amato follows:]

WRITTEN OPENING STATEMENT OF SENATOR D'AMATO

MR. CHAIRMAN, I WOULD LIKE TO WELCOME TO THE JOINT ECONOMIC COMMITTEE THIS MORNING OUR DISTINGUISHED PANEL OF WITNESSES WHO WILL DISCUSS THE ROLE OF GOVERNMENT INVESTMENT IN RESEARCH AND DEVELOPMENT.

THERE CAN BE NO DENYING THE FACT THAT RESEARCH AND DEVELOPMENT EFFORTS HAVE MADE THE UNITED STATES THE INDUSTRIAL GIANT THAT IT IS TODAY. WE CONSTANTLY RELY UPON RESEARCHERS TO KEEP US AT THE FOREFRONT OF TECHNOLOGY. RESEARCH AND DEVELOPMENT IS ESSENTIAL TO THE UNITED STATES IF WE ARE TO REMAIN COMPETITIVE IN THE WORLD MARKETPLACE.

THERE ARE VARIOUS METHODS IN WHICH RESEARCH AND DEVELOPMENT MAY BE STIMULATED AND ENCOURAGED. TWO OF THE MAJOR WAYS TO DO THIS ARE THROUGH REASONABLE TAX CREDITS AND THROUGH FEDERAL FUNDING. PAST EXPERIENCE HAS DEMONSTRATED THAT FEDERAL FUNDING PROVIDES MORE LEEWAY FOR WASTE, FRAUD AND ABUSE. TAX CREDITS TEND TO PROVIDE MORE INCENTIVE TO BUSINESSES INVOLVED IN RESEARCH AND DEVELOPMENT.

I LOOK FORWARD TO THE TESTIMONY OF OUR WITNESSES THIS MORNING AND TO THE INSIGHT THEY ARE SURE TO PROVIDE THIS COMMITTEE ON THE IMPORTANCE OF INVESTING IN RESEARCH AND DEVLOPMENT.

THANK YOU, MR. CHAIRMAN.

Senator **Sarbanes**. Mr. Bloch, we are very pleased to hear from you now.

STATEMENT OF ERICH BLOCH, DIRECTOR, NATIONAL SCIENCE FOUNDATION

Mr. **Bloch**. I have a prepared statement which I would like to submit for the record.

Senator **Sarbanes**. The prepared statement will be included in full in the record.

Mr. **Bloch**. What I would like to do for a few minutes is just highlight some of the thoughts in the prepared statement. First of all, I appreciate the opportunity to testify on science and technology and economic competitiveness.

Your letter addressed four issues: First, the relationship between science and engineering research and economic growth and competitiveness; second, current strategy of U.S. R&D; and third, the human resources and education aspects of our situation. I added a fourth one, knowledge transfer. And I would like to comment briefly on all four of these issues. First I want to make a few comments about the relationship between science and engineering research and economic growth. Since World War II there have been major productivity increases that can be traced back to new technologies and new ideas. Growth in the world economy has been in areas created by new scientific discoveries and engineering innovations and inventions. As examples, I would cite the semiconductor industry, computers, biotechnology, many of the new synthetic materials that we hear so much about.

The shift in the international economy has been facilitated by some of the new technologies, especially communication and transportation, and the shift to a knowledge and information industry is due to new insights and new ideas that only came out of the laboratories 20 to 30 years ago and many even more recently.

It is no longer sufficient to have access to natural resources and cheap labor. Those are no longer the key ingredients for competitiveness in any industry. The new growth industries are essentially the ones that are based on new knowledge, new insights, and they depend on the continuous generation of that new knowledge and that new insight. That is the foundation of many of the new industries that I just mentioned.

Other countries, including our trading partners, understand the situation and, as a consequence, they have increased their investment in science and technology, as you mentioned a few moments ago, Mr. Chairman. As a percentage of GNP, Japan now supports as much basic research in science and engineering as we do.

In fact, I want to make one particular point on that. We should not just assume that Japan will continue to do what it has been doing in the past. The focus in Japan today is on more increase in basic research for one particular reason: As they are catching up with us in many technology areas, they know that they can no longer depend on the generation of new knowledge from this country or from Europe, but they have to contribute to it and that they have to undertake investigations and investments in these areas.

In Europe, there are new programs in information sciences, telecommunications, robotics, and materials, and I think that this represents the technological rebirth of Europe that we probably are not cognizant enough of and are not taking it as seriously as we should.

One example is high-temperature superconductivity. The new developments in high-temperature superconductivity came from all over the world: Switzerland, the United States, China, Japan, and many other countries. It did not come just from one particular country; it came simultaneously from many of these countries.

So, I think there is a new era in the importance of basic research and research in general that the developed countries and developing countries are recognizing and acting on.

The second comment I want to make is on the current state of U.S. research and development and what is the proper mix for that research and development. The central purpose of these hearings on R&D in the United States I think focuses very heavily on that particular issue. So, the question is probably "How are we doing?" and I think the answer is in some ways very well and in other ways not so well. Let me see if I can draw an objective picture.

On the positive side, the strongest and most creative research system in the world is still that of the United States. The explosion of knowledge that has occurred is something that has been very heavily focused on in our universities as well as in some of our industrial research laboratories. There is a shortening of leadtime between basic research and the exploitation of the new knowledge in the marketplace, and we need to be aware of that.

We are not very good in that particular area, by the way. U.S. research leads in many of the new multidisciplinary fields such as biotechnology, materials research, and computer and information sciences—and that is generally acknowledged around the world. Our universities, which combine education and research, are the best in the world, and they focus on both of these aspects, education and research. As a consequence, they attract foreign students and foreign investments in our universities. That again is a sign that part of our system is working very well.

On the negative side, there is a concern about long-term funding trends. There is not enough investment in our universities' basic science and engineering research and education. We are no longer leading the industrialized nations in percent of GNP. Some of the other countries, like Japan and West Germany, have caught up with us in the percent of GNP devoted to research and development.

Your own chart on nondefense R&D has made the point that they are exceeding our investment in those very important areas.

Basic research as a percent of Federal R&D is dropping. It is dropping—and so is, by the way, university R&D dropping—as a percent of our R&D budget. That is primarily because of the heavy defense investment and the fact that the defense R&D budget is not spending a lot of money on basic research or in universities.

So, I want to say something about balance within the Federal R&D budget. It needs some adjustment. And by the way, the doubling of NSF's budget over the next 5 years, which is a request of the administration, is trying to address some of that balance in favor of a more proper mix between basic research and other forms of research and development.

Let me make a couple of other points which I think are very important. The whole national environment for research has improved. Today there is cooperation between universities and industry which did not exist before. Many of the States are getting involved in funding basic research and in funding education at the university level and funding new technologies. I think that is a new trend. There are more cooperative programs between universities and the private sector. Many of the centers that the Foundation has been establishing in the engineering areas are essentially focusing on this cooperation. And there is a strong response from the research community in favor of many of the center activities that the foundation has undertaken.

A third area I would like to comment on is our human resources. People create the knowledge that makes technological innovation possible. The awareness of the importance of people to economic competitiveness is reflected in other nations' investment in human capital.

Japan, for instance, has doubled its technical work force in two decades, and that is a very significant kind of step forward.

U.S. scientific and technical employment has grown three times faster than real GNP and total professional employment, and it is a signal of how important science and technology education and our human resources are in this area.

Scientists and engineers are in demand, and the question is, "Can we meet that demand?" The answer is: "In all likelihood we cannot in the future." We are not generating the human talent that we need. The preparation in high school is not there for many of our students to pursue science and engineering careers later.

It is too late once you get into universities. The college-age population is shrinking. There are fewer students choosing science or engineering as a percent of that college-age population. The number of 22-year-olds is dropping, and as a consequence we must attract a greater portion of the 22-year-olds if we want to supply our industries and government and our universities with the human manpower that we need in the future.

It also means that we need to concentrate on the groups which are underrepresented today in the scientific engineering areas—women and minorities. That is something that the foundation has been focusing on and will have to focus on increasingly in the future.

Today we are highly dependent on foreign students for graduate degree candidates and for people with Ph.D. degrees that later on can enter our work force. Nearly 85 percent of the recent growth in graduate education was due to foreign students. It is very fortunate that we have these students available. Many of them stay here, about 60 percent of them stay here.

But, it is a bad policy to be dependent on a resource over which we have no control. A few years ago we had many Iranian students here. I doubt very much that there are many Iranian students here today. And what can happen with one country can happen with another country.

So, we should not feel secure in the fact that we have a high influx of foreign students and that we are not supplying that talent base ourselves.

Those undesirable educational trends that I just cited—the dropoff in economic competitiveness and the shrinkage of our manufacturing base—could have long-term consequences for us. I refer in my prepared statement to possible American brain drain, and I do not mean literal emigration, but the deterioration of the skill base on which we depend very heavily. As leading industries fall behind, the best people will no longer be attracted to these industries, because there is no economic payoff there.

There are many examples from the past that make that particular point. For example, in nuclear engineering, for completely different reasons, there are very few students today pursuing careers in reactor design and so forth. And this can happen in other industries also as the economic future of these industries is in doubt. I think we have a serious problem in our human resource base.

I said I wanted to comment for a minute on knowledge transfer, a very important item. One of the shortcomings of our industry is a lag between research and product implementation in the marketplace. The point has been made many times that in Japan it is on a much faster track, and I think that is so.

Second, I think there is a lack of coupling between researchers and product developers and manufacturers in the United States. I think that we find many times that Japan and Japanese industry pick up new developments that are flowing out of our universities much faster and much more readily than our own industry does. It is a cultural problem. It is also an attitude problem, and this is something we need to work on.

There are fall guys on all sides, and the United States itself cannot solve the problem, but we are trying to focus on it and help that problem along by making information available and also focusing on programs. I already mentioned the centers program that requires the involvement of industry and not just the involvement of the university. Through this coupling, peer-to-peer coupling between industry people and university researchers, we hope that technology transfer will take place at a faster rate.

So, in summary, let me say a couple of things. First, science and technology are important to the economy, and the universities' health is very important to the health of science and engineering.

Second, we need continuing, steady investment in good times and bad in research and education. It requires a balance between military and civilian investments, between basic and applied programs, between science and engineering, and between support for individuals and support for institutions and centers.

The third item I want to mention is that people are the basic resource. Our educational system needs a major overhaul at the elementary and high school level, and even at the undergraduate level, especially in engineering at the undergraduate level.

We need to attract more students, more women, more minorities into science and engineering. We must demonstrate to young people that the rewards in science and engineering are there. It requires a thriving and model manufacturing sector to make that particular point, however.

Fourth, to stay ahead, we must generate new ideas continuously and convert them quickly to new products and processes. Closer cooperation between the universities and industry is an essential element to make that happen. There must be more focus on timely knowledge transfer, in particular.

Fifth, close cooperation between industry, universities, and Government labs in this is important. That is one way of improving this knowledge transfer.

Last, we need to realize that we are in long-term competition. It requires new relationships, a constant focus on investment and cultural and attitudinal change in our thinking and in our institutions.

Thank you very much.

Senator **Sarbanes**. Thank you very much for a very thoughtful statement and presentation.

[The prepared statement of Mr. Bloch, together with attached charts, follows:]

PREPARED STATEMENT OF ERICH BLOCH

GOOD MORNING. I APPRECIATE THE OPPORTUNITY TO TESTIFY ON THE IMPORTANCE OF SCIENCE AND TECHNOLOGY TO THE NATION'S ECONOMIC COMPETITIVENESS.

SCIENCE AND TECHNOLOGY ARE INSEPARABLE TODAY FROM THE BROADER ECONOMIC PROBLEMS FACING OUR NATION. THE FUNDAMENTAL QUESTION IS NOT WHAT SCIENTISTS AND ENGINEERS WANT OR NEED, BUT RATHER HOW MUCH SCIENCE AND ENGINEERING THE NATION NEEDS IN ORDER TO ASSURE ITS ECONOMIC HEALTH, ITS MILITARY STRENGTH, AND ITS SOCIAL WELL-BEING.

SCIENCE AND TECHNOLOGY ARE CENTRALLY INVOLVED IN THE ECONOMIC DECISIONS WE MAKE. THAT MIGHT NOT HAVE BEEN TRUE TWENTY YEARS AGO, AND CERTAINLY IT WOULD NOT HAVE BEEN TRUE FORTY YEARS AGO. FEDERAL SUPPORT OF SCIENCE WAS LIMITED THEN, AND THE CONNECTION WITH ECONOMIC HEALTH WAS TOO TENUOUS FOR SCIENCE TO BE CONSIDERED SERIOUSLY WHEN MAJOR ECONOMIC DECISIONS WERE MADE.

BUT THAT IS NO LONGER TRUE. THE FEDERAL GOVERNMENT NOW SPENDS IN EXCESS OF $60 BILLION A YEAR FOR R AND D, WHICH INCLUDES EVERYTHING FROM BASIC RESEARCH IN SUPER-CONDUCTIVITY TO THE DEVELOPMENT OF NEW WEAPONS SYSTEMS.

A PART OF THAT TOTAL --ABOUT 12% -- IS DEVOTED TO BASIC RESEARCH IN SCIENCE AND ENGINEERING. BUT THIS IS ESPECIALLY IMPORTANT IN TERMS OF LONG-RANGE IMPACT, BECAUSE THIS RESEARCH, TOGETHER WITH RELATED TECHNICAL EDUCATION PROGRAMS, IS OUR INVESTMENT IN THE FUTURE.

IT IS IMPORTANT THAT WE SEE THESE PROGRAMS AS INVESTMENT RATHER THAN CONSUMPTION. SCIENCE AND ENGINEERING RESEARCH AND EDUCATION ARE CRITICAL INVESTMENTS IN OUR ECONOMIC FUTURE -- AS MUCH SO AS FACTORY EQUIPMENT OR OTHER CAPITAL GOODS. FAR FROM CUTTING BACK IN TIMES OF TIGHT BUDGETS, STEADY INVESTMENT IN GOOD TIMES AND BAD IS AN ECONOMIC NECESSITY.

MY REMARKS THIS MORNING STRESS THIS THEME OF INVESTMENT -- IN OUR RESEARCH PROGRAMS, IN OUR SCHOOLS AND UNIVERSITIES, ABOVE ALL IN OUR PEOPLE.

FOR PEOPLE ARE THE ULTIMATE RESOURCE -- THE MORE SO IN A WORLD IN WHICH IDEAS AND TECHNOLOGIES MOVE EASILY FROM ONE PLACE TO ANOTHER, AND NEW TECHNOLOGIES MAKE "NATURAL RESOURCES" LESS IMPORTANT.

BUT FIRST LET ME SAY SOMETHING TO PUT THESE REMARKS IN THE CONTEXT OF ECONOMIC COMPETITIVENESS.

ECONOMIC COMPETITIVENESS:

IN THE PAST TWO YEARS THE NEED FOR COMPETITIVENESS HAS BECOME CONVENTIONAL WISDOM. AS SUCH, THERE IS A DANGER THAT COMPETITIVENESS WILL GO FROM TODAY'S GOOD IDEA TO YESTERDAY'S SLOGAN SO QUICKLY THAT IT MAY NOT HAVE TIME TO HAVE MUCH EFFECT.

IT WOULD BE A SERIOUS MISTAKE TO LET THAT HAPPEN. TO MAINTAIN OUR STANDARDS OF LIVING, WE SIMPLY HAVE TO PRODUCE MORE, AND DO IT MORE EFFICIENTLY. AND THERE ARE NO QUICK FIXES. WE MUST TAKE A LONG TERM VIEW AND BE PREPARED FOR A TOUGH JOB.

IN PART OUR COMPETITIVENESS PROBLEM IS DUE TO THE SHIFT FROM A NATIONAL ECONOMY TO AN INTERNATIONAL ONE.

WE SOMETIMES FAIL TO APPRECIATE THIS, BECAUSE UNTIL THE LAST FEW DECADES OUR ECONOMY WAS LARGELY ISOLATED FROM THE REST OF THE WORLD. OUR COMPANIES SOLD THEIR GOODS HERE, AND WERE NOT VERY CONCERNED WITH EXPORTING.

NOR WERE IMPORTS A SERIOUS CONCERN. U.S. TECHNOLOGY IN THE DECADES AFTER WORLD WAR II WAS THE BEST THERE WAS IN NEARLY ALL FIELDS. TECHNOLOGICAL INNOVATION -- THE SOURCE OF NEARLY HALF OF OUR PRODUCTIVITY INCREASES -- KEPT US AHEAD.

BUT TODAY THE WORLD ECONOMY IS THOROUGHLY INTEGRATED, AND OUR PRODUCTS MUST COMPETE DIRECTLY WITH THOSE FROM MANY OTHER COUNTRIES.

THIS TRANSFORMATION IS DUE IN PART TO THE INDUSTRIAL RESURGENCE OF EUROPE AND JAPAN AFTER WORLD WAR II, IN PART TO THE SPREAD OF INDUSTRIALISM TO LESS DEVELOPED COUNTRIES, AND IN PART TO COMMUNICATION AND TRANSPORTATION TECHNOLOGIES THAT MAKE WORLD-WIDE INDUSTRIAL INTEGRATION POSSIBLE.

BUT THE MOST IMPORTANT REASON FOR THE TRANSFORMATION IS THE SHIFT TO AN INFORMATION AND KNOWLEDGE BASED ECONOMY. ACCESS TO NATURAL RESOURCES AND LOW-COST LABOR ARE NOT AS IMPORTANT AS THEY ONCE WERE.

IN THIS NEW INFORMATION-BASED GLOBAL ECONOMY, THE NEW BASIC INDUSTRIES ARE COMPUTERS, SEMI-CONDUCTORS, BIOTECHNOLOGY, AND THOSE THAT CREATE NEW MATERIALS FOR SPECIFIC TASKS. THE OLD KEY INDUSTRIES BASED ON NATURAL RESOURCES -- STEEL, COAL, AND OIL -- ARE RELATIVELY LESS IMPORTANT TODAY.

OUR MAJOR COMPETITITORS UNDERSTAND THIS. THEY HAVE SHARPLY INCREASED THEIR INVESTMENTS IN SCIENCE AND TECHNOLOGY AND IN THE NEW KEY INDUSTRIES.

O AS A PERCENTAGE OF GNP, JAPAN NOW SUPPORTS AS MUCH BASIC RESEARCH IN SCIENCE AND ENGINEERING AS WE DO.

O EUROPE HAS DEVELOPED A WIDE ARRAY OF PROGRAMS IN INFORMATION SCIENCE, TELECOMMUNICATIONS, ROBOTICS, AND MATERIALS.

A HIGHLY VISIBLE EXAMPLE OF THIS COMPETITION IS THE RACE FOR HIGH TEMPERATURE SUPER-CONDUCTIVITY. WHAT BEGAN IN SWITZERLAND HAS ALREADY LED TO MAJOR ADVANCES FROM JAPAN, THE UNITED STATES, CHINA, AND SEVERAL OTHER COUNTRIES.

THIS RAPID SPREAD OF IDEAS MEANS THAT NO NATION CAN REMAIN COMPETITIVE WITHOUT INVESTING IN NEW KNOWLEDGE AND TRANLATING IT QUICKLY INTO NEW PRODUCTS AND TECHNOLOGIES.

R AND D INVESTMENT:

YOUR LETTER OF INVITATION INDICATED THAT THE CENTRAL PURPOSE OF THESE HEARINGS WOULD BE TO REVIEW THE STATE OF R AND D IN THE UNITED STATES. IT IS CLEAR THAT:

O WE HAVE THE STRONGEST AND MOST CREATIVE RESEARCH SYSTEM IN THE WORLD, WHICH HAS GIVEN US AN UNPRECEDENTED EXPLOSION OF KNOWLEDGE.

O U.S. RESEARCHERS LEAD IN MANY OF THE NEW MULTIDISCIPLINARY FIELDS SUCH AS BIOTECHNOLOGY, MATERIALS RESEARCH, AND COMPUTER AND INFORMATION SCIENCES.

O OUR UNIVERSITIES -- WHICH UNIQUELY COMBINE RESEARCH AND EDUCATION -- ARE THE BEST IN THE WORLD. THAT THEY ATTRACT STUDENTS FROM ALL OVER THE WORLD, AND INVESTMENT FROM FOREIGN COMPANIES, IS NO SURPRISE. IN THE COMPETITIVE EDUCATIONAL MARKET, THEY DELIVER THE BEST PRODUCT.

ON THE OTHER HAND, LONG TERM FUNDING TRENDS TELL US THAT WE MAY NOT HAVE BEEN INVESTING ENOUGH IN UNIVERSITY BASIC SCIENCE AND ENGINEERING RESEARCH AND EDUCATION:

O WE HAVE GIVEN UP THE COMMANDING LEAD WE HAD OVER OUR MAJOR INDUSTRIALIZED TRADING PARTNERS IN THE FRACTION OF GNP DEVOTED TO R AND D. (FIG. 1) AT 1.9% OF GNP, OUR CIVILIAN R AND D SPENDING IS LESS THAN THAT OF JAPAN AND WEST GERMANY.

O BASIC RESEARCH AS A PERCENTAGE OF TOTAL FEDERAL R&D HAS BEEN DROPPING. (FIG. 2) ONE REASON IS THAT DEFENSE NOW TAKES A LARGER SHARE OF FEDERAL R AND D THAN IN THE PAST -- MORE THAN 70% OF THE TOTAL -- AND DOD SPENDS LESS THAN 3% OF ITS R AND D BUDGET ON UNIVERSITY RESEARCH. (FIG. 3)

O AS A RESULT, THE UNIVERSITY SHARE OF FEDERAL R AND D SUPPORT HAS BEEN DROPPING SINCE THE PEAK IN 1979. (FIG. 4) THIS HAS PUT THE UNIVERSITIES IN DIFFICULTY, SINCE NEW RESEARCH OPPORTUNITIES MEAN NEW DEMANDS FOR PEOPLE, EQUIPMENT, AND FACILITIES. IN BOTH UNIVERSITIES AND INDUSTRY, SCIENTISTS MUST HAVE THE LASTEST EQUIPMENT IF THEY ARE TO TAKE ADVANTAGE OF RESEARCH OPPORTUNITIES.

FORTUNATELY, WE HAVE BEGUN TO REVERSE SOME OF THESE TRENDS IN THE LAST SIX YEARS. TOTAL FEDERAL SUPPORT FOR R AND D HAS RISEN 50% IN CONSTANT DOLLARS SINCE 1980. (FIG. 5)

OVERALL, THE NATIONAL POLICY ENVIRONMENT FOR RESEARCH HAS IMPROVED SUBSTANTIALLY. THERE IS MORE WILLINGNESS ON THE PART OF UNIVERSITIES AND INDUSTRY TO COOPERATE.

WE ARE SEEING MANY STATES GETTING INVOLVED IN RESEARCH

SUPPORT IN NEW WAYS. THERE IS MUCH MORE UNDERSTANDING OF THE NEED FOR BETTER EDUCATION, MORE SUPPORT FOR UNIVERSITY BASIC RESEARCH, AND PROGRAMS INVOLVING INDUSTRY.

AT THE FEDERAL LEVEL THERE IS MUCH MORE EMPHASIS ON COOPERATIVE PROGRAMS. NSF'S NEW ENGINEERING RESEARCH CENTERS AND SCIENCE AND TECHNOLOGY CENTERS ARE PROTOTYPES.

THESE CENTERS ARE LOCATED ON UNIVERSITY CAMPUSES, ARE MULTIDISCIPLINARY, AND HAVE STRONG INDUSTRY INVOLVEMENT. THEY WILL WORK ON BASIC RESEARCH PROBLEMS THAT ARE IMPORTANT TO SCIENCE, BUT ALSO RELEVANT TO INDUSTRIAL TECHNOLOGY.

THE MULTI-DISCIPLINARY EMPHASIS IN THESE CENTERS IS IMPORTANT. MUCH IMPORTANT WORK REQUIRES TRAINING AND EXPERIENCE IN MORE THAN ONE DISCIPLINE. IT MAY BE NO COINCIDENCE THAT SUPER-CONDUCTIVITY WAS DISCOVERED IN A LABORATORY WHERE MULTI-DISCIPLINARY WORK WAS THE RULE RATHER THAN THE EXCEPTION.

LET ME JUST ADD THAT THE RESPONSE FROM THE RESEARCH COMMUNITY HAS BEEN STRONGLY POSITIVE. WE HAVE RECEIVED MORE THAN 800 LETTERS OF INTENT TO SUBMIT PROPOSALS, REPRESENTING ALL DISCIPLINES, A BROAD RANGE OF INSTITUTIONS, HEAVY PARTICIPATION FROM INDUSTRY, AND ALL GEOGRAPHIC REGIONS AND NEARLY EVERY STATE.

IN THIS SITUATION -- WITH MORE THAN $2 BILLION DOLLARS EXPECTED TO BE REQUESTED FOR THE FIRST YEAR OF OPERATIONS -- OUR PROBLEM WILL BE TO SELECT THE VERY BEST FROM AMONG A LARGE NUMBER OF DESERVING PROJECTS.

HUMAN RESOURCES:

NOW LET ME RETURN MORE EXPLICITLY TO THE HUMAN RESOURCES QUESTIONS THAT WERE RAISED IN YOUR LETTER OF INVITATION.

PEOPLE CREATE THE KNOWLEDGE THAT MAKES TECHNOLOGICAL INNOVATION POSSIBLE. THEY RUN OUR INDUSTRIES. THEY ARE THE MENTORS AND TEACHERS OF NEW GENERATIONS OF SCIENTISTS. THEY ARE LEADERS AND DECISION MAKERS IN OUR MODERN TECHNOLOGICAL SOCIETY.

AWARENESS OF THE IMPORTANCE OF PEOPLE TO ECONOMIC COMPETITIVENESS IS REFLECTED IN OTHER NATIONS' INVESTMENT IN HUMAN CAPITAL.

O JAPAN HAS DOUBLED ITS TECHNICAL WORKFORCE IN THE LAST TWO DECADES. (FIG. 6) IT PRODUCES ABOUT AS MANY ENGINEERS ANNUALLY AS WE DO, WITH HALF OUR POPULATION.

O IN THE UNITED STATES, SCIENTIFIC AND TECHNICAL EMPLOYMENT HAS GROWN THREE TIMES FASTER THAN REAL GNP AND TOTAL PROFESSIONAL EMPLOYMENT. (FIG. 7)

CLEARLY SCIENTISTS AND ENGINEERS ARE IN DEMAND, AND THE DEMAND WILL RISE AS OUR MODERN KNOWLEDGE-BASED ECONOMY DEVELOPS.
IT IN NOT CLEAR, HOWEVER, THAT WE WILL BE ABLE TO MEET THAT DEMAND.

O THE NUMBER OF 22-YEAR-OLDS HAS BEEN DROPPING STEADILY AND WILL CONTINUE TO DO SO. (FIG. 8) THAT MEANS THAT UNLESS A GREATER PROPORTION OF THE UNDERGRADUATE POPULATION IS ATTRACTED TO THE SCIENCE AND ENGINEERING FIELDS, THE NUMBER OF SCIENCE AND ENGINEERING DEGREES WILL DECLINE IN THE FUTURE.

HAVING FEWER YOUNG PEOPLE MAKES IT EVEN MORE IMPORTANT TO ATTRACT WOMEN AND MINORITIES TO SCIENCE AND ENGINEERING. MINORITIES ARE ESPECIALLY IMPORTANT, SINCE THEY ARE AN INCREASING FRACTION OF OUR COLLEGE-AGE POPULATION. HISTORICALLY, HOWEVER, THESE GROUPS HAVE HAD LOW RATES OF PARTICIPATION IN THE NATURAL SCIENCE AND ENGINEERING DISCIPLINES.

ANOTHER SERIOUS PROBLEM IS THAT MORE THAN HALF OF OUR NEW PHD'S IN ENGINEERING, AND INCREASING NUMBERS IN MATHEMATICS AND OTHER FIELDS, ARE NOW FOREIGN NATIONALS. (FIG. 9)

OVERALL, FOREIGN STUDENTS ACCOUNT FOR NEARLY 85% OF THE RECENT GROWTH OF GRADUATE EDUCATION IN THE UNITED STATES. WITH FEWER AMERICANS CHOOSING SCIENCE OR ENGINEERING CAREERS, WE ARE INCREASINGLY DEPENDENT ON FOREIGN NATIONALS IN SOME OF THE MOST IMPORTANT SPECIALTIES.

WE ARE FORTUNATE TO HAVE THEM. MANY FOREIGN GRADUATES OF OUR UNIVERSITIES REMAIN TO CONTRIBUTE TO OUR ECONOMY AND TO RESEARCH AND EDUCATION. BUT IT IS BAD POLICY TO BE DEPENDENT ON A RESOURCE WE CANNOT CONTROL.

AS OPPORTUNITIES OVERSEAS INCREASE, WE MAY FIND THAT THE NUMBER OF FOREIGN STUDENTS COMING TO OUR UNIVERSITIES DECLINES, AND MORE OF THOSE WHO DO COME MAY RETURN TO THEIR OWN COUNTRIES.

TURNING THESE TRENDS AROUND WILL BE A LARGE UNDERTAKING. THE DEMOGRAPHIC TRENDS ARE FIXED, AND ATTRACTION RATES TEND TO BE STABLE OVER TIME. MUCH BETTER SCIENCE AND MATHEMATICS IN THE SCHOOLS -- GOOD ENOUGH TO ATTRACT THE BEST STUDENTS -- WILL BE NEEDED.

MANUFACTURING

A SCARCITY OF TECHNICAL PERSONNEL COULD REINFORCE ANOTHER WORRISOME TREND IN OUR ECONOMY: A DECLINE IN EMPHASIS ON MANUFACTURING.

JAPAN HAS TAKEN A LEAD IN MANUFACTURING BY ADOPTING A

SYSTEMS APPROACH THAT INVOLVES THE WHOLE ENTERPRISE. THEY REALIZED FAR MORE QUICKLY THAN WE THAT MODERN MANUFACTURING REQUIRES ATTENTION TO MUCH MORE THAN HARDWARE AND TOOLS. QUALITY AND INVENTORY CONTROL, AND THE EDUCATION AND PARTICIPATION OF ENGINEERS, WORKERS, AND MANAGERS IN DECISIONS ARE AT LEAST AS IMPORTANT.

DESPITE COMMENTS TO THE CONTRARY, MANUFACTURING IS IMPORTANT: BETWEEN 1965 AND 1985, THE DOLLAR VALUE OF MANUFACTURING WORLDWIDE INCREASED 125%. IN EUROPE, THE INCREASE WAS 80%; IN JAPAN, IT WAS 600%. BUT IN THE US, IT WAS ONLY 50%.

IN 1965 THE EEC COUNTRIES' MANUFACTURING TOTALLED ONLY ABOUT A THIRD OF THE U.S. LEVEL. TODAY THEY EXCEED THE U.S.

WE HAVE BEEN TOO WILLING TO WRITE OFF THIS SECTOR. BOTH INDUSTRY AND ACADEMIA CAN SHARE THE BLAME FOR THIS:

O INDUSTRY ALLOWED MANUFACTURING TO BECOME A BACKWATER. THE BEST PEOPLE WENT TO PRODUCT ENGINEERING OR RESEARCH.

O AND IN THE UNIVERSITIES BRIGHT YOUNG ENGINEERS REALIZED THAT THE WAY TO TENURE DID NOT LEAD THROUGH MANUFACTURING RESEARCH. THE SUBJECT SIMPLY DROPPED OUT OF SIGHT -- AND OUT OF THE CURRICULUM -- AT ALL BUT A VERY FEW SCHOOLS.

AN AMERICAN BRAIN DRAIN?

EDUCATIONAL PROBLEMS AND A DECLINE IN MANUFACTURING COULD REINFORCE EACH OTHER TO PRODUCE A "BRAIN DRAIN:" NOT A LITERAL EMIGRATION OF PROFESSIONALS, BUT RATHER A PROGRESSIVE DETERIORATION OF OUR TECHNICAL SKILL BASE.

INADEQUATE EDUCATIONAL SYSTEMS MAKE IT HARDER FOR OUR INDUSTRIES TO COMPETE. IF OUR LEADING INDUSTRIES THEN FALL BEHIND, OUR BEST PEOPLE WILL NO LONGER BE ATTRACTED TO CRITICAL TECHNICAL AREAS. THE ECONOMIC PAYOFF WILL NO LONGER BE THERE. WE WILL FAIL TO DEVELOP NEW SKILLS OR EVEN TO MAINTAIN THOSE WE HAVE.

THE SEMICONDUCTOR INDUSTRY IS A GOOD CASE IN POINT. AS WE LOSE OUR LEADERSHIP POSITION TO JAPAN, THE ATTRACTION OF THE FIELD WILL DECLINE; BOTH STUDENTS AND VENTURE CAPITAL WILL MOVE TO OTHER AREAS. IN THE PROCESS THE NATION WILL LOSE THE LEADERSHIP OF A CRITICAL INDUSTRY.

WE HAVE SEEN THIS HAPPEN BEFORE -- FOR SOMEWHAT DIFFERENT REASONS -- IN NUCLEAR ENGINEERING. HOW MANY BRIGHT STUDENTS TODAY ARE LIKELY TO TRAIN FOR CAREERS IN REACTOR DESIGN OR OPERATION? ARE WE WILLING TO DEPEND ON FOREIGN SOURCES FOR THESE SKILLS?

SUMMARY

MR. CHAIRMAN, LET ME SUMMARIZE BY RETURNING TO THE KEY POINTS RAISED IN YOUR LETTER:

FIRST: RESEARCH AND EDUCATION IN SCIENCE AND ENGINEERING IN THE UNITED STATES ARE CRITICALLY IMPORTANT TO ECONOMIC COMPETITIVENESS. OUR INFRASTRUCTURE FOR BASIC RESEARCH AND EDUCATION -- CHIEFLY OUR UNIVERSITY SYSTEM -- IS HEALTHY AND PRODUCTIVE, BUT ALSO UNDER INCREASING STRAIN.

SECOND: WE MUST MAKE CONTINUING STEADY INVESTMENT -- IN GOOD TIMES AND BAD -- IN RESEARCH AND EDUCATION. THIS REQUIRES THE RIGHT BALANCE OF FEDERAL PROGRAMS:

- BETWEEN CIVILIAN AND MILITARY,
- BETWEEN BASIC AND APPLIED PROGRAMS,
- BETWEEN SCIENCE AND ENGINEERING,
- AND BETWEEN SUPPORT FOR INDIVIDUALS AND SUPPORT FOR

CENTERS.

THIRD: PEOPLE ARE THE BASIC RESOURCE:

O OUR EDUCATIONAL SYSTEM NEEDS A MAJOR OVERHAUL AT ALL LEVELS -- PRIMARY, SECONDARY, AND UNDERGRADUATE -- IN SCIENCE, MATHEMATICS, AND ENGINEERING.

O WE MUST ATTRACT MORE STUDENTS, AND ESPECIALLY MORE WOMEN AND MINORITIES, TO SCIENCE AND ENGINEERING.

O WE MUST DEMONSTRATE TO YOUNG PEOPLE -- ESPECIALLY TO THE BRIGHTEST OF THEM -- THAT THE REWARDS FOR CAREERS IN SCIENCE AND ENGINEERING ARE REALLY THERE. THAT REQUIRES A THRIVING MANUFACTURING INDUSTRY, ACTIVELY CHALLENGING TECHNOGICAL FRONTIERS.

FOURTH: TO STAY AHEAD WE MUST GENERATE NEW IDEAS CONTINUOUSLY AND CONVERT THEM QUICKLY TO NEW PRODUCTS AND PROCESSES.

FIFTH: WE NEED CLOSER COOPERATION BETWEEN THE UNIVERSITIES AND INDUSTRY, OF THE SORT THAT NSF IS SEEKING TO ENCOURAGE THROUGH OUR SCIENCE AND TECHNOLOGY CENTERS PROGRAMS. THIS WILL MAKE BETTER USE OF OUR HUMAN AND FINANCIAL RESOURCES, AND ALSO HELP TRANSFER NEW KNOWLEDGE SMOOTHLY FROM RESEARCH LABS TO MANUFACTURING.

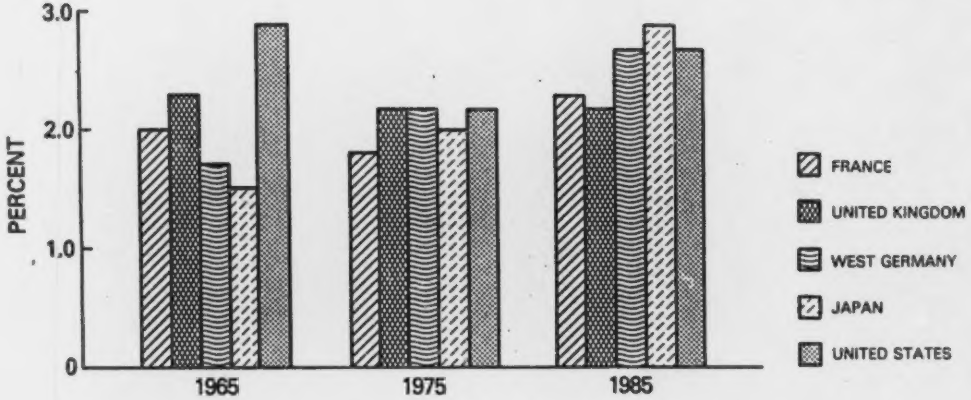
FINALLY, WE MUST UNDERSTAND THAT WE ARE IN A LONG TERM COMPETITION THAT REQUIRES NEW WAYS OF THINKING.

THE RESEARCH COMMUNITY MUST REALIZE THAT FEDERAL SUPPORT IS NOT AN ENTITLEMENT, BUT MUST BE JUSTIFIED BY ITS CONTRIBUTIONS TO NATIONAL GOALS, AND ESPECIALLY TO ECONOMIC COMPETITIVENESS.

PERHAPS THE HARDEST THING IS TO REALIZE THAT SOLVING OUR PROBLEMS WILL REQUIRE MANY DIFFERENT ACTIVITIES, SUSTAINED FOR A LONG PERIOD. NO ONE THING WE DO WILL HAVE A DRAMATIC OR SHORT TERM EFFECT. ONLY A PATIENT EFFORT, LOOKING TO PAYOFF OVER DECADES RATHER THAN YEARS, WILL SUFFICE.

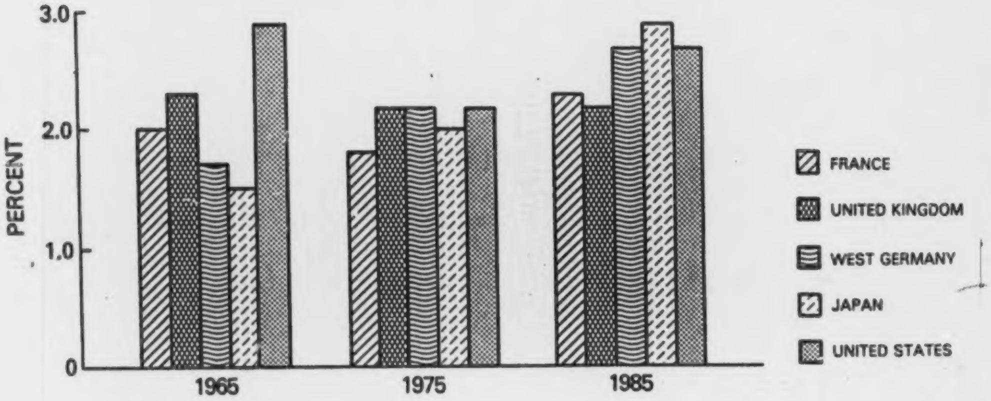
THAT CONCLUDES MY PREPARED REMARKS, MR. CHAIRMAN. I WILL BE PLEASED TO RESPOND TO YOUR QUESTIONS.

R&D EXPENDITURES AS A PERCENT OF GNP FOR SELECTED COUNTRIES: 1965, 1975, AND 1985



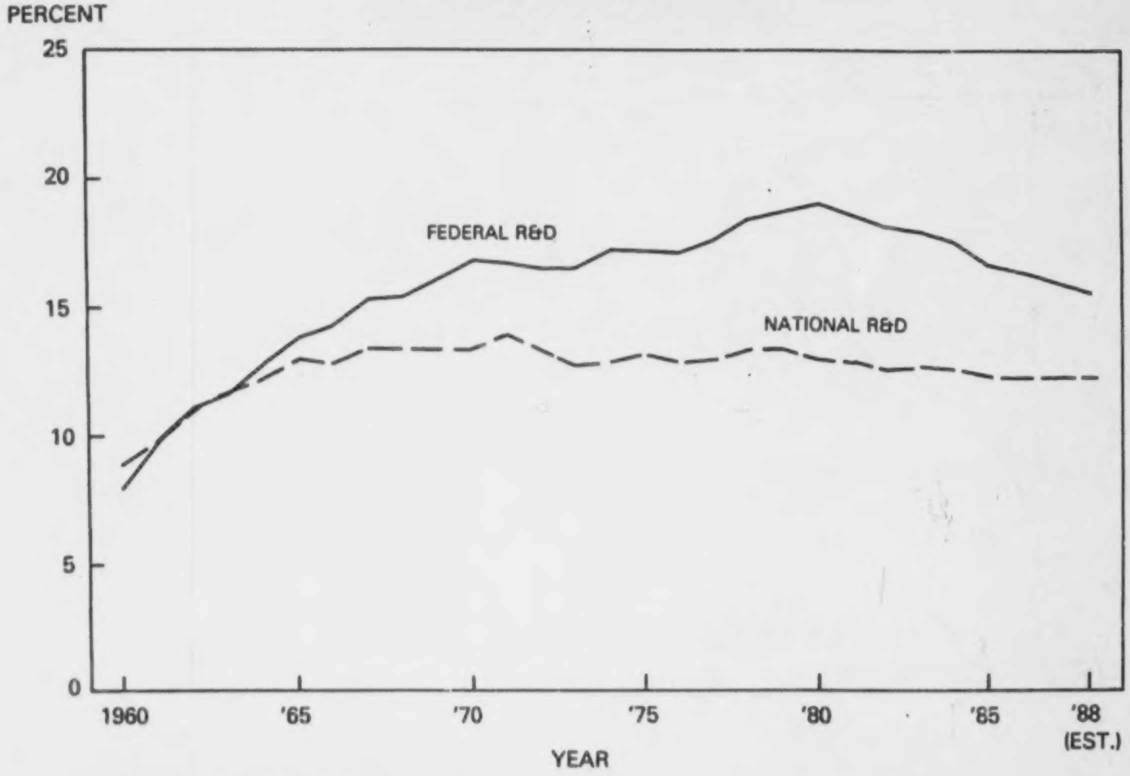
SOURCE: NATIONAL SCIENCE FOUNDATION.

R&D EXPENDITURES AS A PERCENT OF GNP
FOR SELECTED COUNTRIES: 1965, 1975, AND 1985



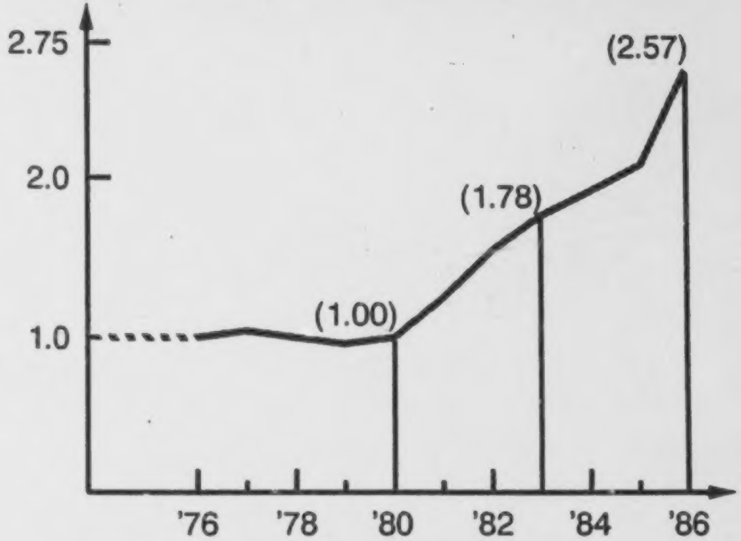
SOURCE: NATIONAL SCIENCE FOUNDATION.

BASIC RESEARCH
AS A PERCENT OF TOTAL R&D



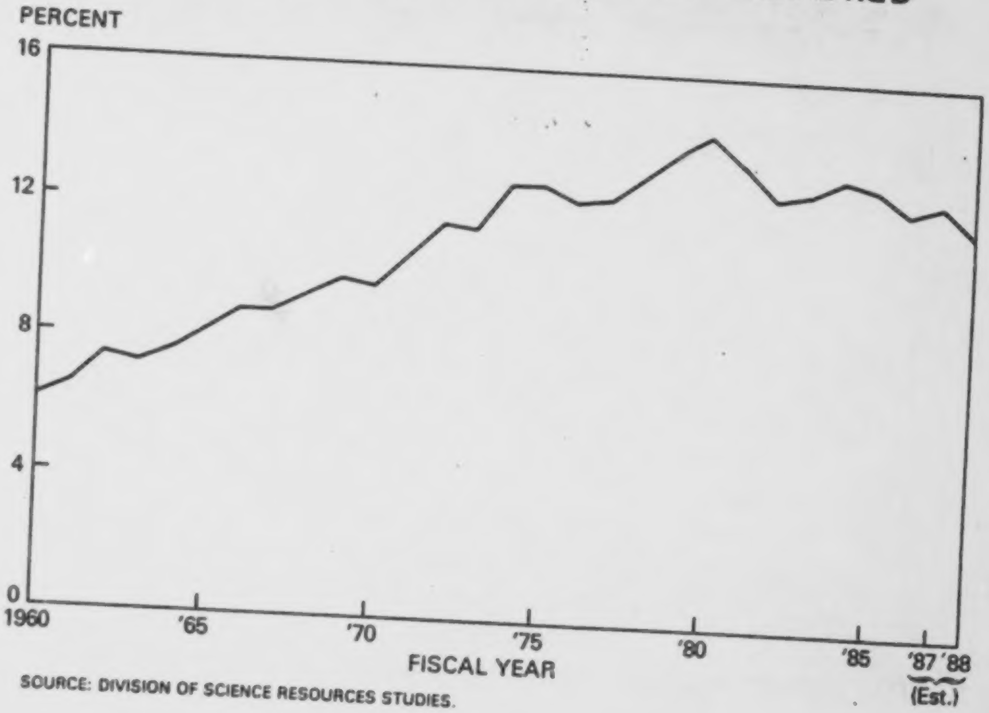
SOURCE: OFFICE OF BUDGET, AUDIT AND CONTROL

RATIO OF DEFENSE TO NON-DEFENSE FEDERAL R&D FUNDS



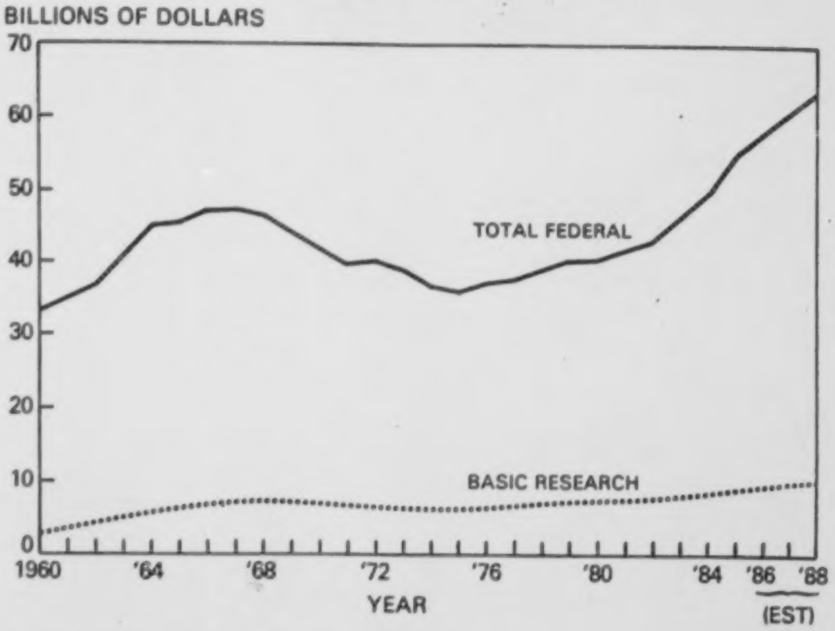
SOURCE: SCIENCE INDICATORS, 1985

FEDERAL OBLIGATIONS FOR R&D AT UNIVERSITIES AND COLLEGES AS A PERCENTAGE OF ALL FEDERAL R&D



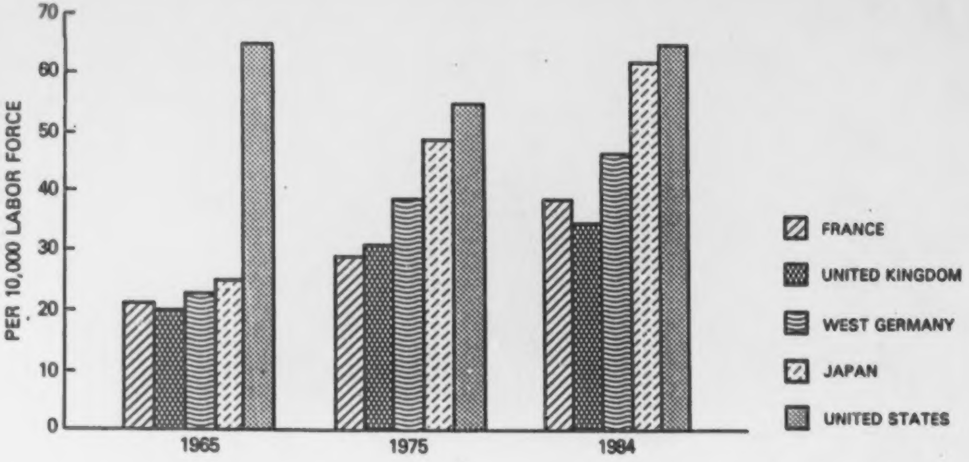
SOURCE: DIVISION OF SCIENCE RESOURCES STUDIES.

TOTAL FEDERAL R&D AND BASIC RESEARCH EXPENDITURES
1960 — 1988
(1987 CONSTANT DOLLARS)



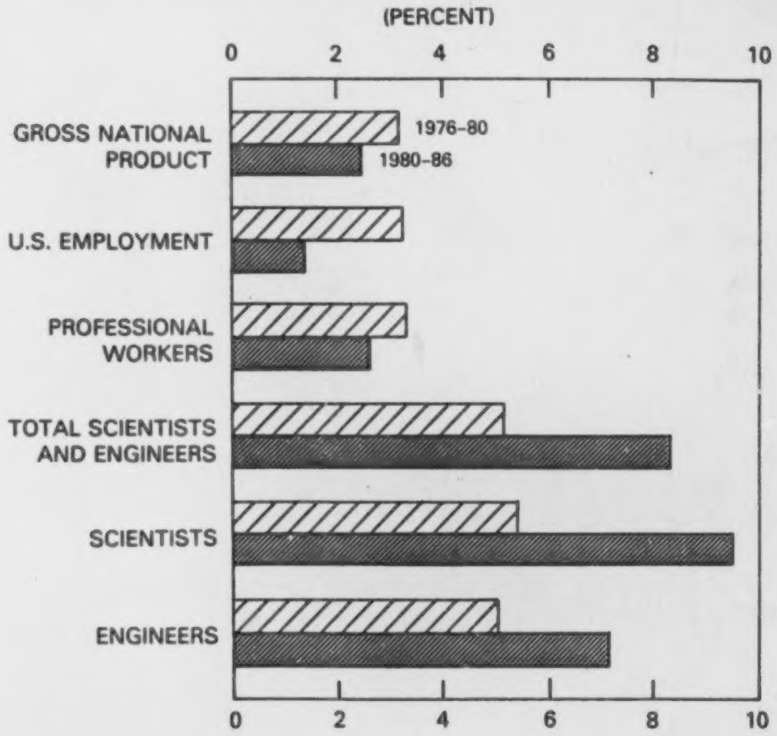
SOURCE: DIVISION OF SCIENCE RESOURCES STUDIES.

R&D SCIENTISTS AND ENGINEERS PER 10,000 LABOR FORCE POPULATION FOR SELECTED COUNTRIES: 1965, 1975, 1984



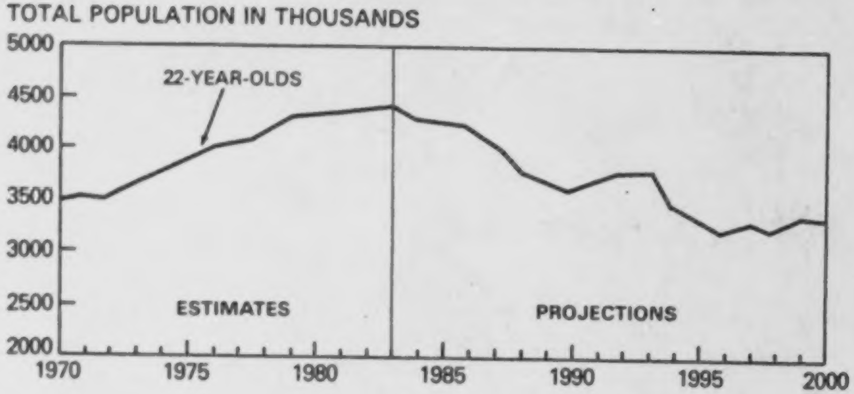
SOURCE: NATIONAL SCIENCE FOUNDATION.

AVERAGE ANNUAL GROWTH [illegible] SCIENCE AND ENGINEERING EMPLOYMENT AND OTHER MANPOWER AND ECONOMIC VARIABLES



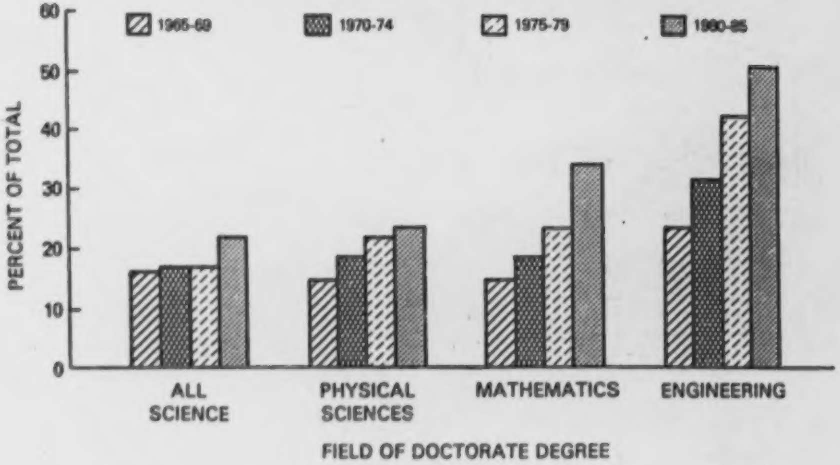
SOURCE: NATIONAL SCIENCE FOUNDATION, SRS

ESTIMATES OF 22-YEAR-OLDS IN THE U.S. POPULATION



SOURCE: BUREAU OF THE CENSUS

DOCTORAL DEGREES AWARDED TO FOREIGN CITIZENS
BY U.S. UNIVERSITIES, 1965-1985



SOURCE: NATIONAL SCIENCE FOUNDATION.

Senator **Sarbanes**. Mr. Bloch, I would like to take just a moment to focus on the charts that you have attached to your prepared statement to the committee. Perhaps if you could just go through them and underscore their significance as you see it in relation to the presentation you made, I think it would be helpful. They are very graphic illustrations of some of these basic points.

Mr. **Bloch**. I would be glad to do that. Let me turn to the first chart. That is R&D expenditures as a percent of GNP for selected countries. You see three timeframes: 1965, 1975, and 1985.

You see that in 1965 we were ahead of the other countries that are shown here: France, United Kingdom, West Germany, and Japan. In 1975 we were equal, essentially. Then, in 1985 Japan exceeds us by a few tenths of a percentage point.

So, the point is that other countries have caught up with us in the investment as measured by this parameter. Obviously we can ask how good the parameter is, and that is a good question. I think it is significant, however, and it is one way of judging different countries.

We need to realize that we live, obviously, in different systems.

Representative **Scheuer**. Are these R&D expenditures for both military and civilian?

Mr. **Bloch**. Yes.

Representative **Scheuer**. How would you evaluate the impact of SDI, if it goes ahead, on the meaning of these charts? For example, as I understand it, SDI last year absorbed 84 or 85 percent of the increase in total R&D expenditures both civilian and military.

Now, if that trend continues, although the United States may be more or less equal to—what is the one just to the left—just to West Germany and only slightly behind Japan, from the point of view of our civilian economy, if an increasing percentage of our R&D is devoted to SDI—and as I said, I think about 85 percent of the increase in R&D both civilian and military went to SDI—wouldn't the reality be a great deal worse than your chart shows for the United States in terms of the strength and vitality and robustness of the American economy?

Mr. **Bloch**. Let me make a general comment first. You have a chart which really underlays the chart that I just discussed by excluding defense R&D spending in all of the three countries. There is not much to exclude in Japan and West Germany, by the way, but quite a bit to exclude in the United States. And you see that on civilian R&D as a percentage of GNP we are well below the expenditure of Japan and West Germany.

Let me make a comment. It is very true that 30 and 40 years ago, in the 1950's, defense led the civilian sector in significant new technology. I give you two examples: computers and semiconductors. The fallout from the defense sector into the civilian sector was very significant. As a consequence there is a whole semiconductor industry and a whole computer industry that really spun off from the investment in defense.

Today, that is no longer the case. Today, in many areas it is the civilian sector that leads the defense sector in many of the materials areas, in computers and semiconductors. Biotechnology—just think about that particular field.

So, the fallout from the defense sector into the civilian sector is no longer as pronounced as it was at one time, and that is a very important point.

Senator **Sarbanes**. That is an extremely important point, because it is sometimes asserted to us when we are focusing on this R&D discrepancy that is up there on that chart in the nondefense area as one of the significant factors for the difficulty we are having in the economic competitiveness area. It is asserted that you get this spinoff or fallout from the defense R&D over into the civilian sector.

I have been exploring this with various major companies who do both defense and nondefense work, and the consistent response I have received from those who are in both fields is that they do not get much of a carryover from their defense R&D into civilian purposes now.

And, of course, you have the other problem of companies that do primarily defense R&D only who have really no vehicle for that transfer. I am talking now about companies that do both so that they at least have an internal vehicle for the transfer, if in fact it is relevant. They find that generally speaking it is not that relevant. Then you separately have the problem of defense contractors almost purely who have no handy vehicle for the transfer even if it was there to be done.

Mr. **Bloch**. That was really the point I was making. We always talk about fallout from defense into the civilian sector. We should talk about fallout from the civilian sector into the defense sector. I think today that is much more prevalent than it was 30 years ago.

Let me make a second point, however. I wouldn't have any problem with investing in defense R&D if defense would spend a bigger portion of their R&D budget on basic research and on education. They are not doing that. If you look at how much defense is spending on basic research, it is about 3 percent. If you had looked 10 years ago or thereabouts, you would find it would have been a much higher percentage. So, they have been dropping. If they would spend more on basic research—as they should because they are depending on the output of basic research—they are depending on the output of our schools for students, engineers, and scientists in order to do what they need to do—then I would not have much of a problem with it.

I am saying within the defense R&D budget the balance isn't right either, the balance between basic research and development and between what they are investing in in universities and in education. If that could be adjusted more toward the 5, 6, 7 percent level, then I think you would see much more fallout from that investment into our civilian sector or into our total society.

So, my problem really with the defense R&D budget is for it to be in balance within the R&D budget and within the Federal R&D budgets, imbalance between basic research and the other areas of research must be corrected.

The next chart that you have in front of you is a chart entitled "Basic Research as a Percent of Total R&D." And you see essentially this particular problem. In the 1980's, despite the fact that there was a very heavy investment in Federal R&D during that time, basic research has not increased proportionately. For instance, if you look at the National Science Foundation, we had a 60 percent cumulative increase over this same period, but because of the heavy shift into defense R&D, basic research took this particular drop.

If one considers the national R&D expenditures that include the private sector—that that one has stayed relatively flat. So there is some contribution from the private sector into basic research.

The third chart——

Representative SCHEUER. What would you consider an appropriate percentage of total research?

Mr. BLOCH. Congressman Scheuer, you are asking difficult questions today.

Representative SCHEUER. What should we be shooting for?

Mr. BLOCH. Let me tell you, I don't think there is an appropriate number. But I will make two points. First of all, at a point in time where we have all of these problems—economic competitiveness, where we know that we are depending on new knowledge, where we know that we are falling behind in human resources—at least this line should stay flat as a minimum. It shouldn't go down. Should it go up? We can have an argument on that. But at least it shouldn't go down. That would be my lower limit on answering your question.

I don't think there is an appropriate number. I think you compare yourself to your competitors. That is one way of finding the truth. The other one is you look at the problems that you have and you ask yourself is your expenditure and is your investment addressing the problem or isn't it? And obviously, when you see this dropoff, then you know you are not addressing the problem that we all agree we have. So, I would answer it that way. I know you wanted a number, but I don't think there is such a number.

The next chart is really the shift between defense and nondefense Federal R&D funds. And you see how that one has increased over the last 10 years.

Senator SARBANES. That is very dramatic. Could we just stop on that for a moment?

Mr. BLOCH. Sure.

Senator SARBANES. I see you have extended the trend line to the left. So, I take it, over a sustained period of time it was at about a 50-50 split.

Mr. BLOCH. 50-50. Right.

Senator SARBANES. And in recent years we have had a very marked shift, so we now have a 2.57 ratio of defense to nondefense Federal R&D funds.

Mr. BLOCH. Right. That was the 70 percent that you mentioned before. And again, underneath this shift is what my concern is as to what is the right investment. But underneath that is essentially the imbalance between basic research and the rest of R&D.

Senator SARBANES. You have a shift from nondefense to defense; and within defense you have a shift away from basic research, which compounds the problem.

Mr. BLOCH. That's right. That is exactly right. I don't think, for instance, that it would make any difference if the National Science Foundation or if the Department of Defense would invest in basic research. The results might be the same. I think we can do it better, by the way, but that is a self-serving kind of a comment.

Senator **Sarbanes**. You are entitled to self-serving comments.

Mr. **Bloch**. Thank you, Mr. Chairman. [Laughter.] The next chart you see is similar to one that I showed you before, but this one is Federal obligations for R&D in universities and colleges as a percent of the Federal R&D budget. And you see the same trend. Since 1980 this has gone down. Even so, again on an absolute-dollar basis, the increases have been very significant in this area.

The next chart shows Federal R&D in basic research expenditures in constant 1987 dollars. You see the increase in the total Federal budget, and you also see basic research essentially staying more or less flat or having a much lower slope of increase, in constant 1987 dollars. The same point really that I made before is illustrated.

The next series of charts really has to do with human resources: R&D scientists and engineers per 10,000 of labor force in the various countries over, again, three timeframes: 1965, 1975, and 1984. And you see in 1965 we had a predominant advantage in that regard. Our technical labor force as a percent of the total labor force was much higher than any of the other countries that we are showing here.

By 1975, you see them in catchup, and in 1984 you see Japan almost equalling us on this very important parameter. These are scientists and engineers, in the labor force, be they in Government or be they in the private sector.

So, you see them catching up and you see the result of more investment in Japan and some of the other countries in R&D in these very important areas. That is really what this chart reflects.

Representative **Scheuer**. May I ask a question?

Mr. **Bloch**. Sure.

Representative **Scheuer**. If it is true that Japan is training twice the number of scientists and engineers that we are training, with half the population, why isn't Japan way ahead of us in scientists and engineers per 10,000 labor force?

Mr. **Bloch**. Watch out. That is not quite correct. Japan is generating twice the number of engineers, not the number of scientists and engineers. OK. I think that is the problem. And by the way, there are also great differences between engineering fields. So, it is a factor of two that really only applies to engineering. But there might be more behind this one than meets the eye, I just don't know.

The next one that you are shown is called "Average Annual Growth, Science and Engineering Employment and Other Manpower and Economic Variables." This is in the United States for two timeframes. The light area is 1976 to 1980, and then the heavy, shaded area, 1980 to 1986. And really, if you look about halfway down, total scientists and engineers—these are growth figures; these are not absolute figures—you see that in both timeframes the growth here has exceeded U.S. employment goals. And you see it is a reflection here of a more technical kind of an industrial environment and more need for scientists and engineers in our labor force.

The point I wanted to make is there is no reason to believe that this will not be the case in the future. It would meet other things if it were going in the other direction, therefore we need to be concerned about whether we can supply this work force, not only the numbers but also the quality of that work force.

Both the quality and the quantity is important, and one cannot make predictions on how many scientists and engineers are needed; one always could be wrong. But the indication here is essentially what the trend is, and we need to be aware of that particular trend. Again, there is no single number that you can focus on, but I think that you can focus on the trend and try to understand what is going on.

The next one is the estimate of 22-year-olds in the population. That has been written about and talked about for a long time. We are in the middle of a drop in the number of 22-year-olds, and it is interesting that if you go back historically and ask yourself what percent of the 22-year-olds are pursuing science and engineering careers, that number hasn't changed very much over time. It has stayed fairly constant. So, trying to influence that number would be a difficult task.

Senator SARBANES. So, your previous chart shows that the need for scientists and engineers is increasing.

Mr. BLOCH. Right.

Senator SARBANES. And this chart shows that the potential population from which to draw scientists and engineers is decreasing.

Mr. BLOCH. Right.

Senator SARBANES. So, unless we can somehow significantly raise the percent who choose to move into science and engineering, we are going to face a major gap.

Mr. BLOCH. Right. That's the point.

The other point I want to make is we have some underrepresented groups, and I made that point in my statement before—women and minorities, in particular—from which we need to attract more into science and engineering. The representation of women in science and engineering has increased over the last 10 or 12 years significantly, but it seems to be leveling off.

In the minorities area, we have not made very much progress, to be very frank about it. Even though we have focused on that area, we need to focus more on it.

Another source, obviously, of input into this talent pool is our foreign citizens, and the last chart talks to that particular point. It shows you how over the last 20 years, since 1965 to 1985, especially in engineering, we have been depending on Ph.D. candidates and Ph.D. students from foreign countries to supply our own need and our own replacements, not just ours but theirs, obviously.

But a large number or a large percentage of the people stayed here, and my concern is that that might shift as industries develop in other countries and their capabilities develop, and people might no longer stay here to the same degree that they did before.

That essentially is the content of the charts.

Senator SARBANES. Thank you very much, sir.

I have a vote. I have one question, and then I will turn it over to Congressman Scheuer.

You said earlier that we weren't very good in transferring the knowledge from basic research into applied research, as I understand it, or into products. And you subsequently said that it was a cultural and an attitude problem. I wonder if you could develop that a little bit. Why aren't we doing well?

Mr. **Bloch**. I don't know the answer to that, but let me try to describe the situation. And, by the way, let me say that I have observed that even within a single company, the relationship between the research division, or the research laboratory, and the product development laboratory is not a cooperative one; even within a company, there is a hesitancy to accept input from the outside.

The Japanese have no problems reading everybody's books and everybody's papers and learning from them, and asking questions, and so forth, apparently.

But we have a tremendous problem in that regard. That is one thing. The second one has to do with the speed at which you move into new areas and develop new products.

Senator **Sarbanes**. Could I go back to your first point?

Mr. **Bloch**. Sure.

Senator **Sarbanes**. Is it an attitude that comes from having been No. 1?

Does any historical research show that in an earlier time in American history, when we were not No. 1, a different attitude prevailed with respect to willingness to learn from others, in being open to absorb everything? We had such dominance in the post-World War II period, is it that kind of an attitude?

Mr. **Bloch**. I am pretty sure that is a big part of it. The other part of it is that people didn't feel that they had a competitive pressure; that competitive pressure was from inside the country; it was not from the outside.

And that is a little bit different. Now, it shouldn't be probably, but it is. That has something to do with it.

The third one has to do with the fact that probably there were enough resources available to redo many things. You didn't have to take the output from another group and use it yourself; you could develop it yourself.

That has something to do with it. And the urgency of it has something to do with it. And I think all of these things combined lead to what I call the cultural problem.

Senator **Sarbanes**. Thank you very much.

Congressman Scheuer.

Representative **Scheuer**. Mr. Bloch, your testimony has been extremely thoughtful and helpful, and I appreciate it very much.

When you talk about doctoral degrees awarded to foreign citizens, are you talking about foreign students who have come here and who have received their green card and are working under a student visa and intend to make the United States their home?

Or are you talking about foreign students, for example, a country like China, where the overwhelming percentage of them are expected to come back? There may be a little attrition around the edges, but from the point of view of our society, they are lost to us once they graduate.

Which is it?

Mr. **Bloch**. I was talking about both of them. And I mentioned the point that, today—especially in engineering—about 60 percent of that student body stays here more or less permanently. You never know whether it is permanent completely or not.

So I have talked about both, essentially.

Representative SCHEUER. What you have here for 1980 to 1985, the last column on the right, in engineering, half of our engineering students are foreign.

Mr. BLOCH. Careful, these are doctoral degrees. These are not undergraduate engineers. The picture is completely different at the undergraduate level.

Representative SCHEUER. Would it be more or less?

Mr. BLOCH. It would be fewer foreign students.

Representative SCHEUER. As a percentage.

Mr. BLOCH. Right.

Representative SCHEUER. Of the doctoral students, half of them are foreign and half of them are going to stay. So, in effect, we will have the benefit of 75 percent of the doctoral students in engineering for our society.

Mr. BLOCH. Yes, that is correct.

Representative SCHEUER. Looking at the face of our universities, our schools of engineering—Harvard, MIT, Cal-Tech, Carnegie Tech, and so forth—it is an increasingly Asian face, wouldn't you say? A growing percentage of Asians in that——

Mr. BLOCH. There is a growing percentage of Asians in both the graduate student population as well as in the faculty.

Representative SCHEUER. Now, to me, that would be a fascinating subject. It would be a very welcome phenomenon, as far as I am concerned, if most of them would stay here and be part of our society.

On the undergraduate level with its increasingly Asian face of our student body, what is the prospect or what are the statistics on the number of those students who have come from Taiwan or mainland China or South Korea, or whatever? And who are going to make America their home, who would be part of our pool of scientific talent in the years to come, as a percentage?

Mr. BLOCH. What is the percentage in the total population? In the total engineering population?

Representative SCHEUER. In the undergraduates, what percentage of the undergraduates who are forming the undergraduate students in science, math and engineering?

What percentage of them will continue to be in our pool of scientific talent of all kinds?

Mr. BLOCH. I don't know the numbers, but let me say one thing. If you look at the undergraduate population, you see a different kind of a situation. Foreign students are not that prevalent.

Representative SCHEUER. Are not that prevalent?

Mr. BLOCH. That's right. Now, it's true that Asian students that are born in the United States—Hispanic students, obviously, are——

Representative SCHEUER. They are not foreign.

Mr. BLOCH. They are not foreign. They are increasing. But, if you look at the foreign undergraduate population, I have not seen any numbers that make that a very prevalent kind of a ——

Representative SCHEUER. Most of the Asian students who are in the college or even postgraduate work in science, math and engineering, most of them are American citizens who were born here.

Mr. **Bloch**. No. In the graduate areas, it is different. In the graduate areas, what I showed you here is true.

Representative **Scheuer**. Students studying for their engineering degrees, undergraduate engineering degrees.

Mr. **Bloch**. I think that is very small for the foreign population. Maybe, 5, 6, 7, 8 percent, something like that, but nowhere near 50 or anything like that.

Representative **Scheuer**. Very good.

Mr. Bloch, there are some things that Congress can do, and a few things that we can do well, and a lot of things we can't do at all, or that we can't do very well even if we try.

In terms of encouraging more students to go into science, math and engineering and then, when we get them into science, math and engineering, encourage them to go into basic research. And then, when they graduate from school with all of their degrees going into the civilian sector in basic research, that would be the great desideratum.

Does Government have enough tools which we can aim with precision at that problem?

Mr. **Bloch**. I think you have enough tools. I don't know if they are being used. Obviously, the big things that Congress can do and that Congress does is allocating budgets to those areas that need it.

And I would recommend that you double the foundation's budget, as an example.

Representative **Scheuer**. What else?

Mr. **Bloch**. That is one thing.

The second thing, which is very important, is consistency. And what I mean by that, it doesn't help us to get a 20-percent increase 1 year and then have 3 or 4 years with no increases.

There has to be some kind of a consistency of investment going on, and that is something that Congress certainly could do. And that is why we asked for a long-term commitment to the foundation's budget, a 5-year view, so that we know what we have to deal with and can deal with, that the students know what they can depend on, that the researchers know what they can depend on. It is the on again/off again funding that is very discouraging because research is not done in a day; research is done over many years.

Education isn't done in a day. Education is done over 20 years. So there has to be some consistency. And if Congress wants to do one thing in particular—be more consistent from year to year—and give us more of the view of the next 5 years at least and not just a view of the next 12 months.

By the way, this is 1988 and we still don't have a budget after 3 months into the fiscal year 1988. This makes it very difficult to deal with with some of these issues.

Representative **Scheuer**. Well, I can tell you that serving on the Science and Technology Committee as I do in addition to this committee, I feel for you and I sympathize with you.

You are talking about two discrete problems—one, consistency, and the other future funding. Looking at the world as it exists. And as Grover Cleveland said over a century ago, we are faced with a condition and not a theory. The condition is that Congress is going to be very reluctant to give up its authority to scrutinize budgets on an annual basis, and give any institution out there, whether it is the Defense Department or anybody else, a 5-year funding.

Some of us are pushing for a 2-year funding, which would be a quantum jump forward. So, as a practical reality, I don't hold out much hope for your convincing any of those institutions out there convincing Congress that we should, in effect, let go of the power of the purse for long periods of time and, in effect, give up a good deal of our oversight clout.

But, in terms of consistency, one would hope that even though we hold on to our annual appropriations, which we probably should shift to a 2-year cycle anyway, but even if we hold more or less to the current practice, we still ought to be consistent.

We still ought to have long-range goals and they ought to come out of the hearing process and the appropriations process. And we should try to stick to them. And we haven't.

Mr. Bloch. Can I comment on this, Congressman Scheuer?

Representative Scheuer. Of course.

Mr. Bloch. I understand that. And that would be nice. But, that is not what I had in mind. I didn't have in mind a 5-year appropriation bill for the foundation. It would have helped in 1988 if the Science and Technology Committee in the House would have acknowledged the 5-year doubling of the National Science Foundation's budget. In principle that would have helped a great deal.

It is an authorization bill. It is not money. It's not money in the bank. It is not a blank check. You could have—you wouldn't have given up your oversight at all. Next year is another hearing. And if you think you made a mistake, you could have adjusted it at that time.

The Senate authorization committee has done more than the House Science and Technology Committee in that regard. I was not focusing on the appropriations process. I was focusing more on the authorization.

That would have been a signal, just like the President and OMB gave the signal when it agreed to a 5-year doubling of the foundation's budget. It doesn't mean that we're going to get it. But it is a better starting point of negotiations and a better starting point of considerations than if you come in every year and you start from scratch.

That's what I had in mind.

Representative Scheuer. Yes, I agree with you.

In terms of specific goals, pinpointing specific goals, like increasing the number of students who go into basic research, would you recommend that we create a specific incentive program and create a large number of postdoctoral fellowships, let us say, NSF postdoctoral fellowships for basic research—science, math and engineering?

Or how else would you encourage the trend toward more basic research?

Mr. Bloch. Let me make a couple of points.

For instance, the foundation has plans for doubling the number of graduate fellowships we support. We can only do that if we get this doubling of the foundation's budget because these are expensive kinds of programs.

We have a second goal, namely, to increase the number and size of grants that we give individual investigators, so that the individual investigator can support more graduates, fellows and postgraduate fellows than what we can today.

Today, on an average grant, which—it is difficult to talk about averages because they vary all over the place, but I will do it anyway—today, an average grant, a principal investigator can support only about one-tenth of a graduate student. That is not enough.

If you could increase the grant size, increase the number of grants, then that would have an effect, a direct effect on both graduate students as well as postgraduates.

I think that is a good vehicle because now you are combining research and human resource generation together. And I think that is the right way of doing it.

Representative SCHEUER. If we were to do that, should we specify that those fellowships should be for basic research and in the civilian sector?

Mr. BLOCH. No, I don't think you need to specify that. You know that the basic research the foundation supports is important to the civilian sector as well as to the defense sector; because we are talking about basic physics, basic mathematics, engineering, and so forth. I don't think you need to specify.

Representative SCHEUER. If the situation that I outlined briefly on SDI is accurate, the overwhelming percentage of the basic research going on in this country, like 84 or 85 percent, or at least the increase in basic research, is 84 or 85 percent SDI.

And it seems to me that—so you have really frozen nonmilitary research, basic research, at more or less its current level, with virtually all of the increase going to SDI.

Mr. BLOCH. Coming back to my comment before, if a big portion of the SDI budget would go to basic research and would go to support education in universities, that would be all right.

You would add to the pool of educated scientists and engineers and you would add to the knowledge pool that is applicable across the board.

If the research is in a very narrow area which is divorced from the civilian sector and if it doesn't support education, that's when I think we have a problem.

Representative SCHEUER. OK. Thank you very, very much, Mr. Bloch. Your testimony has been really outstanding and we appreciate it.

Mr. BLOCH. Thank you.

Representative SCHEUER [presiding]. And now we will ask Mr. Albert Teich of the office of public sector programs of the American Association for the Advancement of Science to come forward.

Mr. Teich, we are happy to have you with us. And why don't you take 8 or 10 minutes to speak with us informally. Your testimony will be printed in full in the record. And then I am sure we will have some questions.

STATEMENT OF ALBERT H. TEICH, HEAD, OFFICE OF PUBLIC SECTOR PROGRAMS, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Mr. Teich. Thank you, Congressman Scheuer. I appreciate this opportunity to appear before you at this hearing on R&D issues. I have been asked to discuss trends in R&D funding. My testimony will serve to underline many of the points that were made so effectively by Erich Bloch.

My testimony is based on the work of my colleagues and myself at the American Association for Advancement of Science, the AAAS.

As you know, AAAS is a national organization with 130,000 individual members, representing all fields of science and engineering. Most people know us through our flagship publication Science magazine. But, each year, in collaboration with a group of about 20 scientific, engineering and higher education associations, we prepare an analysis of R&D in the budget. The material that I submitted in advance to you is an excerpt from this year's report, which was published in March.

But I should make clear that the views that I am going to express here today are my own and not necessarily those of the association.

This is a timely subject for the Joint Economic Committee to explore. R&D is the engine of economic growth as economists, including this year's Nobel Laureate, Robert Solow, have established. And the Federal Government supports about half of the country's R&D.

In the proposed fiscal year 1988 budget, the total for R&D is about $67 billion. In the few minutes that I have, I just want to sketch for you very briefly a few features of this enterprise.

As Senator Sarbanes indicated in his opening statement and as you discussed with Mr. Bloch, the largest part of Federal R&D is in the defense area—just under three-quarters of Federal R&D spending is actually in defense, most of it in DOD and some of it in the atomic energy defense activities portion of DOE.

This is a different situation, a very different situation than we had at the beginning of the Reagan administration and prior to that, when the split was more like 50–50.

I should point out, by the way, as you know, that R&D in the budget is not a single item. It is not a pie that is divided up among different agencies. What we call the R&D budget is really an after-the-fact construct, the result of many individual decisions which are arrived at more or less independently.

That is an important aspect of the budget process as it applies to R&D.

During the past 7 years, the administration has recommended each year a large increase in defense R&D while, at the same time, has held most areas of nondefense R&D either flat or reduced.

There have been a couple of exceptions to this in basic research, NSF being one of them. Each year, Congress has cut back the proposed increases in defense R&D and restored some of the cuts in nondefense R&D, but the result, nevertheless, has been a progressive, consistent shift in this split from 50–50 to about 70–30.

I have brought along a few slides, which I'm going to show on that screen.

Representative SCHEUER. Excuse me; 50–50 to 70–30?

Mr. TEICH. Fifty-fifty prior to 1981. And it has now shifted to 70–30. As you already have discussed, these charts present much of the same kind of information that——

Representative SCHEUER. Off the record.

[Discussion off the record.]

Representative SCHEUER. Back on the record.

Mr. TEICH. We have here a breakdown of R&D by functional component showing the levels for the past several years and the proposed level for fiscal 1988.

The slide also includes fiscal year 1967 for reference. That was the time that R&D funding peaked as a fraction of GNP. And you can see the blue portion at the bottom and the bottom segment of each of those bars is the defense portion of R&D.

The other portions, the green is space, yellow is health. The little purple slice is energy. And then you have general science in green, and everything else is in the orange piece on the top. And you can see here the large and growing share of defense R&D in this picture.

This next picture shows you the same information translated into constant dollars. And one of the most interesting features of this is the difference in space R&D between 1967 and 1988. As you can see, the major difference between the R&D picture in 1967 and the current day is the tremendous amount we were spending on the Apollo program at that time.

That is no longer part of the picture. Today, space is a much smaller part of the R&D picture. And defense, as you can see, has grown consistently.

Let's turn to look more closely at the current picture rather than simply the change over a period of time, which we discussed at a considerable extent.

The next slide shows the R&D budgets for fiscal year 1986, 1987, and 1988 for the major Federal R&D agencies. As you can see, note that the slide only shows six agencies. While most Federal departments and agencies do perform some R&D, these six—DOD, Health and Human Services, Energy, NASA, NSF and the Department of Agriculture—those six account for about 95 percent of all Federal R&D.

What is most obvious in this slide, of course, is the size of the defense R&D budget relative to any of the other nondefense agencies.

Note, in fact, the size of the proposed increase, the yellow bar there, in the President's proposed budget for fiscal 1988. The blue and green are fiscal 1986 and 1987. And note the increase between 1987 and 1988 in Defense Department. Just the increase is larger than the total R&D budget of any of the civilian agencies.

In fact, the changes in the civilian agencies don't really show up on this scale because they are dwarfed by the defense budget. So what we have to do is take DOD out of the picture if we want to look at those and expand the scale.

The top of the scale here is $50 billion. If we expand this on the next slide to a scale where the top is about $9 billion, you can see somewhat more clearly the differences, the changes, ups and downs in the different civilian agencies.

And I have added in here EPA and the Department of Transportation. And what you can see in this is the administration's proposed reduction in HHS, which is NIH's research. A small proposed reduction in energy. A small increase in NASA. The NSF increase reflects the first year in the administration's proposed doubling of the NSF budget.

But you also see how small the changes are, as I say, relative to the changes in defense. I'm not going to give you the details to three decimal places for each of these agencies. We don't have the time and the details are in the materials that I submitted.

Also, the numbers are going to change as a result of congressional action, since we are talking about proposed levels here. Eventually, these numbers will settle down when the final action is taken on the budget.

And I will be happy to supply detailed information if the committee requires it on request.

But, instead, I want to look at another important aspect of the picture and one that was also highlighted in Mr. Bloch's testimony. And that has to do with the character of R&D work as shown in the next slide.

The term R&D, as you know, encompasses a broad range of activities. At one end of this range, it is the professor, the proverbial professor sitting alone in his or her office with a pencil and paper, maybe a PC these days, and at the other end, it is an elaborate ICBM test firing with thousands of personnel involved—support personnel, technicians, scientists, planes, ships, and so on.

Basic research serves to advance the cutting edge of knowledge, while development serves an entirely different purpose, that of applying knowledge and know-how to practical problems.

Defense and nondefense R&D, as you have discussed with Mr. Bloch, are totally different in this regard. Defense R&D is mainly D. Actually, it is DT&E—development, testing, and evaluation.

As you can see on this slide, this breaks down the defense budget from 1981 through 1988 into its components. Basic research is in blue at the bottom. You can barely—you have to have pretty good eyes to see that. Applied research is the green portion.

Above that, development, which is the yellow piece, and that is the largest by far. And then the little piece on the top is R&D facilities.

And what you can see here is, first of all, development accounts for by far the largest share of defense R&D. Basic research and applied research are really quite small relative to development.

And what you also see is that most of the growth since 1981 has been in the yellow portion, in the development portion, as you discussed.

Now, nondefense R&D is more evenly divided among the three components. The pattern of change as seen in this change, where blue is basic, green is applied, yellow is development. And then the purple slice is facilities.

What you can see here is the impact of the Reagan administration's policies, which favor reducing the Federal role in nondefense development while giving favored treatment to many areas of basic research.

In fiscal 1981, as you can see, nondefense development was the largest component of nondefense R&D. Today, basic research is the largest. And I think, as you were getting at in the last witness's testimony, we do ourselves something of a disservice when we talk about total, the Federal R&D as an organic entity and use it as some kind of an indicator.

We need to be more discriminating and look within total R&D at basic research, applied research, at these components and at the civilian/defense split to really understand what is going on in R&D funding in the Federal Government.

Before I conclude, I want to highlight several issues that I think merit the committee's attention. I put these in the category of macroissues, since they relate to the R&D budget as a whole, rather than to individual agencies.

The first has to do with the balance among functions. As I said a moment ago, R&D is not a pie that gets divided up among different functional areas. But, nevertheless, talking about an R&D budget is still a reasonable thing to do because it is a good indication of how we allocate scarce resources for R&D.

In this light, it is not only fair, but I think it is essential to ask if the ratio of defense in R&D to nondefense R&D reflects their relative value to our society.

It is also important to ask about the balance within the nondefense R&D budget. For example, whether we ought to be spending four times as much on basic research in NSF.

Perhaps the answer will be yes. But, if it isn't, we ought to examine the alternatives.

The second point I would like to make has to do with what some observers have called "mortgages" on the R&D budget. During the past several years, we have initiated a number of large-scale programs. If these are carried through to completion, they are going to have substantial budgetary impact over a period of many years.

These include the SDI, space station, the superconducting supercollider, the Genome project, the national aerospace plane, and, to a lesser extent, the S&T Centers program in NSF.

We need to think about how we are going to fund the runout costs of all of these programs simultaneously in a constrained budget environment without squeezing out a whole lot of other R&D activities.

The third issue I want to raise——

Senator **Sarbanes** [presiding]. May I interject there?

Mr. **Teich**. Yes, please.

Senator **Sarbanes**. Another possibility would be to squeeze out one of these programs, in which case, you would be able to fund a lot of other R&D activities.

Mr. **Teich**. That is certainly——

Senator **Sarbanes**. To follow up on Congressman Scheuer's earlier question.

Mr. **Teich**. No question. But I think that we often—perhaps we have been getting into some of these programs without thinking through the consequences of their simultaneous runout costs. And certainly not doing one of them is one way to handle those consequences.

Let me speak now to the issue of competitiveness because I think, this year, you really cannot go anywhere in this town anyway without hearing or reading about it and how important R&D is to the potential solution of the problem.

One of the things that our budget figures reveal—I haven't taken the time today to bring it out—one of the things they reveal is how little Federal R&D really goes for work that supports the goal of competitiveness.

The new NSF S&T Centers program is one piece that does. Other pieces include some of the work of the Bureau of Standards, some of NASA's work on space commercialization, and bits and pieces throughout various agencies.

But, on that slide that I showed you a few minutes ago, scaled for the total R&D budget, the total of those competitiveness-related activities would barely be visible.

The last point I want to mention has to do with the overall budget, and it has to do with planning for growth. If we are going to continue even a few of the large programs that I mentioned—not all of them, but even some of them that I mentioned a moment ago—if we're going to double NSF's budget, as NSF and the administration have advocated, and as the President has promised, and if we are going to use Federal R&D to address the competitiveness challenge, then the R&D budget is certainly going to have to grow.

The problem of the deficit, as you well know, looms over any of these plans for growth. I have taken a look at the agreement between the President and the joint leadership of Congress and it provides for an increase of only $3 billion in budget authority in all discretionary domestic spending between fiscal 1988 and 1989.

How one is going to accommodate growth—in the R&D budget, much less any other areas of domestic spending—under such constraints is a problem that must be faced.

That is all that I want to say in my statement.

Thank you. I will be happy to answer your questions.

Senator **Sarbanes**. Thank you very much.

[The excerpt of the report referred to in Mr. Teich's statement follows:]

AAAS REPORT XII

RESEARCH & DEVELOPMENT FY 1988

Intersociety Working Group

American Association for the Advancement of Science
1333 H Street, NW, Washington, DC 20005

Chapter 1

Overview and Policy Issues

American Association for the Advancement of Science

Albert H. Teich, Stephen D. Nelson, Jill H. Pace, Susan L. Sauer

For those who have followed research and development in the federal budget for the past several years, FY 1988 holds few surprises. Just as the Administration's overall budget is similar to the proposals it has put forth during past few cycles, so too, the R&D components echo familiar themes. Once again, there are big increases in defense R&D, some expansion in space and general science, and reductions in energy technology and some areas of civilian applied research. The only new wrinkles are in health research at NIH, where the Administration has proposed what on the surface looks likes a big increase but is, in fact, a reduction, and at NSF, which has been promised a doubled budget within five years.

This overview (1) examines R&D in the context of the total federal budget; (2) reviews the major features and trends in the FY 1988 budget proposals for R&D; and (3) discusses the prospects for these R&D proposals in the Congress and their implications for the nation and the R&D community.

A. Political and Economic Context of the FY 1988 Budget

Although budgetary politics continue to occupy center stage in Washington, the crisis atmosphere surrounding the Gramm-Rudman-Hollings (GRH) law has eased, and a certain ennui has begun to set in. The deficit still looms over the Capitol, and while it is far from solved, it does seem to be shrinking rather than growing. The economy meanwhile has not only failed to collapse under the weight of the deficit, but -- despite a variety of reasons for long-term pessimism -- has been bouyed by a remarkable Wall Street rally during the first two months of the year.

The legislative creativity which produced Gramm-Rudman-Hollings in 1985 also allowed Congress to find ways to meet the letter of that law in 1986 without either raising taxes or subjecting domestic programs to the kind of draconian cuts that many had feared. (For details on how this was accomplished see Congressional Action on R&D in the FY 1987 Budget, AAAS, December, 1986.) Nevertheless, the proverbial "other shoe" that has been expected to drop on the federal budget for some time still remains suspended in mid-air and the possibility of major reductions remains.

Congressional action on the FY 1987 budget resulted in a level of defense spending substantially below that which the President had requested, a level of nondefense spending considerably higher than requested, and no tax increase. Although the budget met the GRH deficit target of $144 billion on paper, the actual deficit is likely to be much higher -- up to $173 billion according to recent OMB estimates. While this is disappointing to some observers, it nevertheless represents a major reduction compared to the FY 1986 deficit of $221 billion.

With this as background, the Administration followed the pattern it has established over the past several years in proposing its budget for FY 1988. It chose to present a budget that makes a political statement -- a strong reaffirmation of the policies and priorities it has proposed and Congress has rejected annually since 1981 -- rather than putting forth a realistic blueprint for government activity that acknowledges Congressional preferences.

The budget meets the GRH deficit target of $108 billion without a major tax increase, while providing growth in defense outlays about 2 percent above the level of inflation (the smallest defense increase in the six years of the Reagan Administration). It achieves this by proposing reductions and terminations in a variety of nondefense programs (most of which Congress has already rejected several times) and by assuming numerous asset sales and other one-time revenue generating devices. Although many specific elements of the budget will certainly be enacted, few in the Congress took its overall architecture seriously. The Congressional Budget Office has estimated, furthermore, that the budget would actually yield a deficit of $134 billion, some $26 billion above the target.

In the budget and the President's associated policy proposals, the Administration has given special prominence to programs that address the need to improve the nation's position in the international marketplace -- i.e., its economic competitiveness. This has raised the salience of R&D and science, mathematics and engineering education in policy discussions. It also provides a context for continued preferential treatment for R&D in the budget, something the R&D community has enjoyed for the past several years.

Table I-1 shows the composition of the entire FY 1988 federal budget (in outlays) in both current and constant dollars. As can be seen in the table, defense R&D is slated to grow considerably faster than overall defense spending (nearly twice as fast, in current dollars), while nondefense R&D is treated much better than the "other government" outlays category of which it is a part.

Projections for the next five years, derived from figures in the FY 1988 budget indicate that the Administration would continue to treat R&D well, should its preferences hold sway over that period. Table I-2 shows these figures, which should be taken with a large grain of salt. On the defense side, R&D is projected to increase about 10 percent in FY 1989, then drop back somewhat before resuming its climb in FY 1991. On the nondefense side, R&D would continue to grow, despite overall shrinkage in the "other government" category.

B. R&D in the FY 1988 Budget

Tables I-3 through I-9 provide information on several important aspects of the Administration's requests for R&D in the FY 1988 budget, while Table II-1 displays a comprehensive summary of the R&D requests of the major federal agencies. Tables II-2 through II-21 provide detailed information on agency budget requests. Analyses of these agency budgets and cross-cuts by discipline will be found in Parts II and III of this report.

As a point of departure, Table I-3 compares the figures for budget authority, obligations and outlays for defense and nondefense R&D in the FY 1988 budget. (See "General Notes" at the front of this report for definitions of these terms.) In the request for defense R&D, both budget authority and obligations are slated to rise nearly 17 percent over FY 1987, while outlays increase a bit more slowly, 11 percent. Nondefense R&D shows a nearly 15 percent rise in budget authority in FY 1988 request, while obligations and outlays would increase by less than 3 percent over FY 1987. The sharp difference here is due to the NIH situation, discussed below. When the NIH budget is adjusted for comparability with prior years, the overall increase in budget authority for non-defense R&D is only 0.2 percent in current dollars.

Other highlights of the FY 1988 budget revealed by our tables include the following:

- Despite the appearance created by the NIH anomaly, the divergence between defense and nondefense R&D continues. As shown at the bottom of Table I-3, budget authority for FY 1988 national defense R&D would increase nearly 13 percent over FY 1987 in constant dollars. Nondefense R&D budget authority appears to increase almost 11 percent in constant dollars, but when the NIH figures are adjusted, this translates into a 3.4 percent decline.

- Finer structure in the nondefense side of the budget is revealed in Table I-4 and Figures 1.1 and 1.2, which show the major functional components of federal R&D funding in current and constant dollars. Aside from the anomalous increase in health R&D, space and general science are also slated for significant increases, while energy and the "all other" category (including environment, transportation, and development assistance R&D among others) decline.

- Within defense R&D, the largest increases are in development (which in DOD includes test and evaluation programs). This area would increase by 18 percent (14 percent in constant dollars), while applied research would grow 6 percent (3 percent in constant dollars) and defense basic research would rise 3 percent (a 1 percent decline in constant dollars). This situation is similar to that of the past several years. (See Table I-6 and Figures 1.3 and 1.4.)

- The 35 percent increase in budget authority for R&D in NIH stands out among agencies. (See Table I-7.) Subtracting the "advanced appropriation" to adjust the NIH figures for consistency with prior years, however, reveals that budget authority for NIH is actually slated to decline by about 10 percent (in current dollars). Other R&D programs in the Department of Health and Human Services, including those in ADAMHA

Figure 1.1

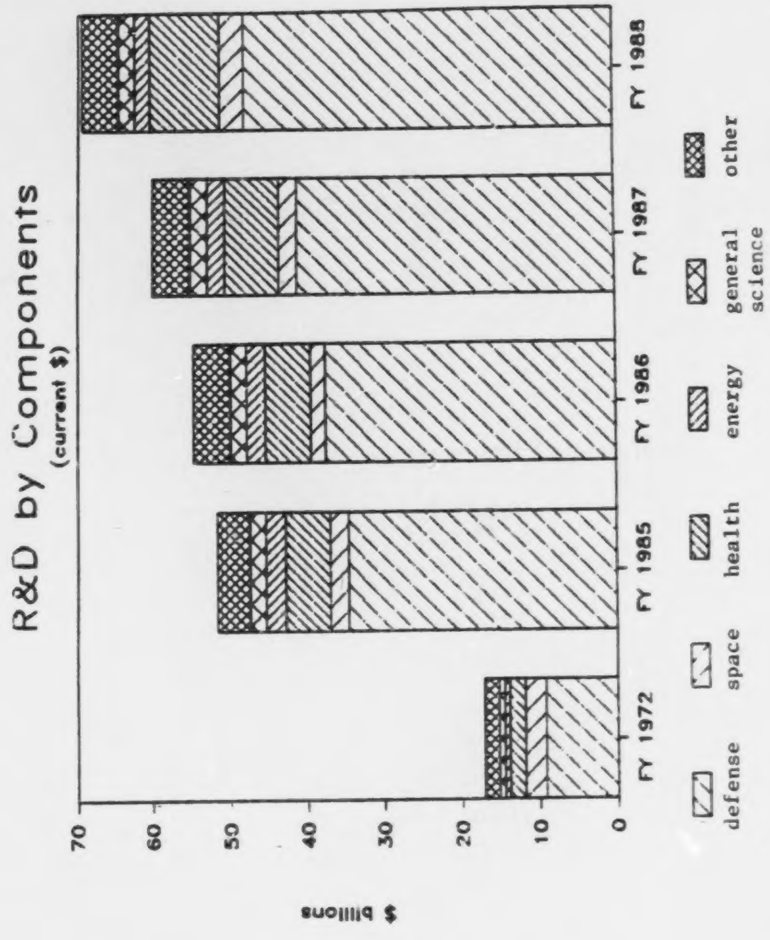

R&D by Components
(current $)
$ billions
70
60
50
40
30
20
10
0
FY 1972
FY 1985
FY 1986
FY 1987
FY 1988
defense
space
health
energy
general science
other

Figure 1.2

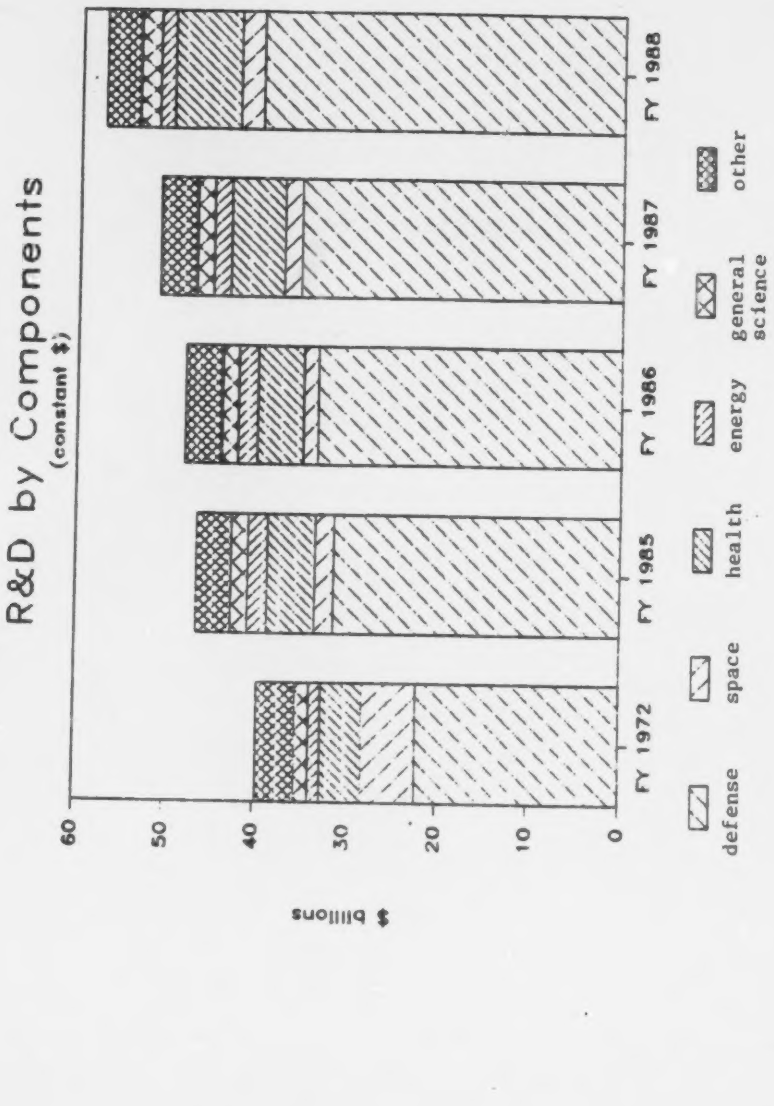

R&D by Components
(constant $)
$ billions
0
10
20
30
40
50
60
FY 1972
FY 1985
FY 1986
FY 1987
FY 1988
defense
space
health
energy
general science
other

Figure 1.3

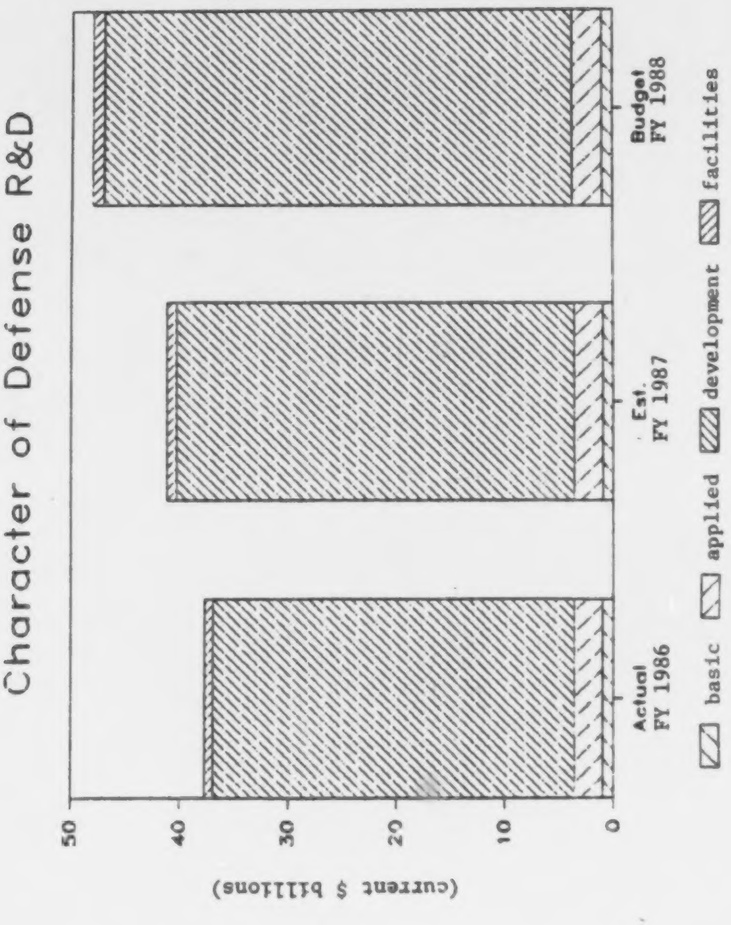
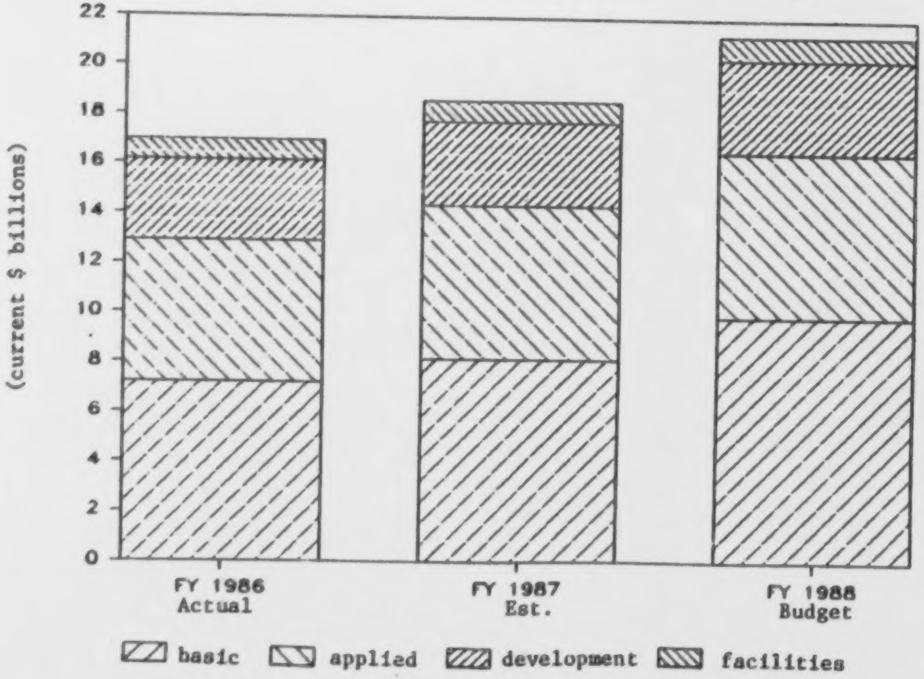

Character of Defense R&D
(current $ billions)
50
40
30
20
10
0
Actual FY 1986
Est. FY 1987
Budget FY 1988
basic
applied
development
facilities

Figure 1.4

Character of Non-Defense R&D



and the Centers for Disease Control are slated for substantial cuts (down 14 percent in current dollars, 17 percent after adjusting for inflation). See the next section for further discussion of NIH.

- General science programs in DOE (high energy and nuclear physics) are due for a 13 percent increase (9 percent in constant dollars). The DOE budget does not include any construction funding for the Superconducting Super Collider (SSC), for which a go-ahead decision was announced after the budget was released. Funds for initiating this project in FY 1988 -- should Congress approve it -- would need to come either from reprogramming or a supplement to the original budget request.

- NSF R&D is set to go up nearly 17 percent (about 13 percent in constant dollars). The increase provides funding for NSF's rapidly-growing Science and Technology Centers program, as well as sizeable increases for the Engineering Directorate and the new computer and Information Science and Engineering Directorate, emphasizing programs geared toward economic competitiveness. In presenting the FY 1988 NSF spending plan, the Administration also indicated that it plans to double the agency's budget over the next five years, following the recommendations of the Packard-Bromley Report.

- NASA's R&D request shows a rise of 15 percent (11 percent in constant dollars). New funding is deovted to development activities for the Space Station, and a new Civilian Space Technology Initiative (within the Office of Aeronautics and Space Technology) to rebuild NASA's technical strength. The NASA budget also includes R&D funding to correct defects in the Shuttle's solid rocket booster system and improve other elements of the Space Transportation System. Along with this, the safety, reliability and quality assurance program receives a boost of 76.1 percent over FY 1987.

- Once again, civilian energy R&D in DOE is recommended for a substantial cutback (10 percent in current dollars, 13 percent in constant dollars). Solar and other renewables, fossil fuels and conservation programs are all affected. Worth noting, however, is the fact that the proposed cut is less drastic than it has been in recent years. (A 38 percent reduction was proposed in DOE's energy technology programs last year.)

- R&D in other agencies comprise a mixed bag. USDA shows a 5 percent reduction (current dollars), while EPA, USGS and Education are up slightly. Showing impressive consistency, the Administration has, for the seventh successive year, proposed terminating the Sea Grant Program. This is reflected in a 23 percent cut in NOAA's R&D budget. Congress, equally consistent, seems likely to restore these funds, as it has for the past six years.

- Basic research -- heavily influenced by the NIH anomaly -- shows a staggering 20 percent increase, over 15 percent in constant dollars (see Table I-8). However, if one considers about 2/3 of the proposed $2.7 billion "advance appropriation" for NIH to be basic research, and subtracts it from the NIH figures (to make them comparable with prior years), then the picture looks much different. Under this assumption, budget authority for basic research is essentially level in current dollars (up 0.5 percent) and down slightly (3.4 percent) in constant dollars. The picture is similar in estimated support for R&D at colleges and universities, shown in Table I-9. Both of these items are discussed in more depth in Chapter 2.

- In sum, the overall picture for R&D funding in the proposed FY 1988 budget is similar to recent years and reflects consistent application of the Reagan administration's policies: heavy investment in military development, test and evaluation, emphasis on nondefense basic research, particularly in areas of physical sciences and engineering, and resistance to strong Congressional pressures to increase basic biomedical research in NIH.

C. A Note on the NIH Situation

Although the budget for health research is discussed in detail in Chapter 5, the NIH situation requires discussion here because of its significance in overall R&D picture. For the past several years, Congress has been pressing more money on NIH than the Administration has wanted to spend. Last year, the Administration proposed a budget which cut R&D in NIH by about 5 percent. Congress responded by adding more than a billion dollars to the request, yielding an increase in NIH R&D of nearly 18 percent over FY 1986.

In its FY 1988 budget request for NIH, the Administration did two unusual things which it said were intended to "stabilize" NIH support for invesigator-initiated projects. First, it transferred $334 million in FY 1987 budget authority to FY 1988, calling it "extended availability of funds" rather than a deferral. Second, it proposed to add an extra $2.7 billion in FY 1988 budget authority to fund "outyear commitments generated by the award of competing research project grants," terming the new funds "advanced appropriations." The funds would not be obligated until FY 1989 and 1990. At the same time, it requested a reduction in regular NIH budget authority below the appropriated level for FY 1987.

The pros and cons of these proposals -- as well as their prospects for Congressional approval -- are discussed in Chapter 5. What is important to note here is that the "advanced appropriations" create a $2.7 billion anomaly in the proposed levels of budget authority for NIH R&D in FY 1988. Figures on budget obligations and outlays, however, are not affected by the situation.

Most of the budget figures employed in the AAAS R&D Reports are in budget authority, since this is the form in which Congressional appropriations are made. Other R&D budget analyses, including OMB's "Special Analysis J" and the NSF statistical series use obligations for their budget data. Usually, the trends in budget authority and obligations are similar, but the NIH situation this year means that our figures present a much different picture than one gets from these other budget analyses.

To make our FY 1988 budget data consistent with other years, it is necessary to subtract the $2.7 billion "advanced appropriation" from the NIH figure. We have indicated this in footnotes to the tables where it is relevant and also mentioned it in various places in the text. We have also adjusted basic research and figures and R&D in colleges and universities by amounts proportional to their respective shares of total R&D in NIH. The $334 million of "extended availability" funds are included in FY 1987 budget authority. Under the Administration's proposal, they would be not be obligated until FY 1988.

D. Prospects for R&D in FY 1988

Several factors are likely to influence Congressional action on R&D in the FY 1988 budget. First, of course, is the overall budget situation. Although the likelihood of arbitrary across-the-board reductions to meet deficit targets seems small compared to what it was a year ago, concern over the deficit remains high and the President remains adamantly opposed to a tax increase. The pressure to reduce controllable expenditures, including R&D, is going to continue and budget-cutting fever could easily strike the Congress at some point during the session.

On the other side is the favored position that R&D continues to occupy in the policy environment. With growing attention focusing on industrial competitiveness and the role of R&D in enhancing it, this position may even improve in the coming months and could help to sustain support for R&D budgets (at least in areas seen as relevant to industrial technology) in the face of budgetary pressures.

Beyond these factors are the specifics of agency proposals and situations. The Administration's proposals for NIH immediately stirred up a storm of controversy and seem unlikely to be approved in their present form. Consideration of the NSF budget seems likely to focus on expansion of the its Science and Technology Centers program, on its supercomputer program, and perhaps on science and mathematics education as well. The recent Presidential decision to proceed with construction of the Superconducting Super Collider will doubtless dominate discussions of DOE's basic research and perhaps affect consideration of other basic research programs as well. Congressional views of the Strategic Defense Initiative will have a major impact on DOD funding for R&D. A host of issues face NASA, including plans for the space station, the need for a diversified launch capability, and long-range goals for the space program.

In all, the outlook is mixed. A substantial number of important issues are unresolved and their resolution could have major impacts on the R&D community. The overall budget landscape seems to be improving, although it is still fraught with dangers. Despite being relatively "controllable" among government expenditures, R&D seems well-placed. At worst, things seem better than might have been expected a year ago.

Chapter 2

Special Analyses

American Association for the Advancement of Science
Stephen D. Nelson, Jill H. Pace, Albert H. Teich, Susan L. Sauer

Four important areas of R&D trends are covered briefly in this chapter: federal funding for basic research, federal support for R&D at colleges and universities, R&D in industry, and national patterns in R&D, for both sources of R&D support and performers. The tables relevant to these discussions are found at the end of Part I.

A. Basic Research

Strong support for basic research has been an explicit theme of federal science policy under the Reagan Administration, and language reaffirming that support in the FY 1988 budget and beyond can be found in more than just the usual sources. Besides the predictable references in Special Analysis J (Research and Development) in the federal budget documents and the statements of the President's science advisor, this theme received special attention in the President's State of the Union Address, in the detailed backup documents for the Address, in the Administration's bill regarding trade and economic competitiveness, and in budget justification statements for the National Science Foundation asserting a commitment from the Administration to double NSF's funding over the next five years. This ought to be comforting for those scientists and research administrators harboring residual doubts about the sincerity and stability of the Administration's commitment to federal support for basic research.

On the other hand, a look at the budget figures for FY 1988 reveals that the Administration's support for basic research -- although still significant in the face of severe budgetary constraints -- is not as robust as suggested by its statements nor as emphatic as might appear at first. A casual look at the figures (see Table I-8) seems to show federal support for basic research increasing by nearly 20 percent, from just over $9 billion in FY 1987 to $10.8 billion in FY 1988. However, a closer look discloses that nearly all of the apparent increase is accounted for by the anomaly in proposed funding for the National Institutes of Health (NIH), the "advanced appropriations," discussed in Chapters 1 and 5. If one assumes that within the advanced appropriations ($2.7 billion for R&D) the proportion of basic research is about the same as that for the NIH budget as a whole (64 percent), and subtracts out that dollar figure ($1.7 billion) from the NIH total for basic research, for comparability with prior years, the apparent increase in federal support for basic research virtually disappears. The FY 1988 total then becomes almost $9.1 billion, or less than one percent over FY 1987 levels in current dollars, and a decline of 3.4 percent in constant dollars.

The NIH anomaly has significant implications for a number of key trends and patterns discussed in this chapter and others, and we have tried to alert the reader -- both by footnotes in the relevant tables, and by our discussion of the trends -- to the potential for misleading conclusions.

Basic research has enjoyed significant growth in recent years, both in current and constant dollars, as shown in Table I-5. Its proportion of total federal R&D support has gone from 10.5 percent in FY 1967 to 12.9 percent in FY 1972, to about 15 percent in the past several years. For FY 1988 the Administration's proposals would give basic research about 15.6 percent of total federal R&D, but subtracting out the portion contained in the NIH advanced appropriations reduces this share to 13.6 percent.

It should be noted that the figures for basic research shown in the tables are not actually direct budget proposals, but estimates of basic research funding derived from proposed budget data. Agencies present their requests in programmatic terms, then estimate the amounts that would be spent on different types of R&D based on those requests.

In recent years approximately 90 percent of federally supported basic research has been of a nondefense rather than defense nature, as shown in Table I-6. Defense basic research has grown relatively little in recent years, actually decreasing from FY 1986 to FY 1987. A slight increase is proposed for basic research funded by DOD in FY 1988. Nondefense basic research, much larger in absolute terms, would be about the same as FY 1987 (a 0.3 percent increase) when one eliminates the NIH advanced appropriations part.

Table I-8 shows basic research support by agency. NIH -- the largest single federal supporter of basic research -- has been discussed above, but it is important to note that apart from its advanced appropriations, NIH basic research would actually decrease 6.8 percent in FY 1988, to $3.4 billion. This figure would represent about 37.3 percent of all federally supported basic research, as compared to the 40 percent figure that has characterized NIH in recent years.

The largest true growth in basic research for FY 1988 would take place in the National Science Foundation (NSF), whose primary mission is support of basic research. NSF has successfully hitched its wagon of budget justification to the rising star of economic competitiveness, and claims to have won a commitment from the Administration for a series of significant yearly increases that would double the Foundation's budget over the next five years. This may seem like good news to many, but before excitement among basic scientists grows too rapidly, it is well to remember (1) that Congress must act on such requests each and every year, and (2) that the current Administration cannot commit succeeding administrations -- Republican or Democratic -- to such a goal.

To round out the picture of basic research support in the largest R&D agencies, the Department of Energy would receive a modest increase in support for basic research, while support in NASA and the Department of Agriculture would be virtually the same as in FY 1987.

Details regarding the specific effects of these trends within each of the agencies can be found in the other chapters in Parts II and III of this book.

B. Colleges and Universities

The pattern here for FY 1988 parallels that discussed above for basic research: namely, expressions of strong support by the Administration for R&D in these areas; budget proposals which seem to show significant increases; and evidence of some actual slippage in budgetary support, when the NIH anomaly is factored out. Nevertheless, when one considers the extraordinary pressures to reduce the federal budget deficit, the continued support for this potentially vulnerable part of the budget could be seen as encouraging to academic scientists and administrators. The Administration's rationale is stated in Special Analysis J, Research and Development:

> Support for basic research at universities serves the dual role of providing new knowledge and helping to ensure the future availability of high-caliber scientists and engineers. Both of these are key elements in the long-term ability of the nation to compete in global markets.

Turning to the data, shown in Table I-9, the picture, by agency, is mixed. It should be emphasized that these data do not represent direct programmatic decisions, but are after-the-fact estimates of how much funding is likely to go to colleges and universities under program levels contained in the budget request.

Once again, NIH is the central player, accounting for 48.0 percent of all federal R&D support to colleges and universities in FY 1987. But again, what looks like a substantial increase for NIH in this support is due to the anomaly of the advanced appropriations request. When this is removed (a reduction of over $1.6 billion), the figure for NIH becomes $3.1 billion, a decrease of 13 percent from FY 1987 levels. That level, however, would still account for 44.0 percent of all federal R&D support for colleges and universities in FY 1988.

NSF, with an increase in support for colleges and universities of 16.6 percent in FY 1988, would regain the number two spot in terms of agency support of this type, after having fallen behind the Department of Defense in this category in the mid-1980s. DOD itself would receive a modest increase of 6.2 percent to nearly $1.2 billion. One element of DOD support of considerable interest to colleges and universities is the University Research Initiative, which is proposed for FY 1988 to return to about the $90 million level, after a drop in FY 1987 to $34 million. This is described more fully in Chapter 3.

NASA's support for R&D in colleges and universities would increase by almost 10 percent to nearly one-third of a billion dollars. College and university R&D support would be sharply cut, however, in the Departments of Energy and Agriculture -- by 20.8 percent and 17.5 percent, respectively. Details on the programmatic cuts associated with these agency trends can be found in the respective agency chapters elsewhere in this book.

Overall, the total of federal R&D support to colleges and universities in FY 1988 appears to be increasing by nearly 17 percent, to somewhat over $8.7 billion. But correcting for the case of the NIH advanced appropriations puts the figure at $7.1 billion, a decrease of 5.0 percent in current dollars and 8.4 percent in constant dollars.

C. R&D in Industry

The National Science Foundation's Division of Science Resources Studies tracks industry spending on R&D. Based upon data provided by NSF and collected for its series on National Patterns of Science and Technology, this report is able to provide estimates of industrial spending on R&D. These data, however, are not directly comparable with other figures in this report, since among other things they refer to calendar years rather than fiscal years. The data are presented in Tables I-10, 11, 12, and 13.

Table I-11 shows R&D spending by different sources of funds, including industry, since 1975. Industry has provided a generally increasing proportion of total national R&D spending since the early- to mid-1970s. It surpassed federal spending for R&D by about 1980, and reached approximately 50 percent of total national spending by the mid-1980s. The estimate for calendar year 1987 shows a slight decrease in this proportion, from 50.0 to 49.0 percent, reflecting the fact (shown in Table I-10) that federal R&D support has grown faster in the past two years than that from other sources. Particularly impressive is the fact (shown in Table I-11) that industrial R&D spending has nearly doubled in constant dollars in the past 12 years.

Who receives this massive support? Primarily industry itself -- 97.6 percent of the R&D spending provided by industry is performed by industry. Another recipient that has attracted increasing attention over the past several years is the academy -- much has been said and written urging closer collaboration on R&D between industry and colleges and universities. Table I-10 shows an estimated level of spending by industry for college- and university-performed R&D of about $746 million in 1987, an increase of nearly 46 percent over the previous two years. However, this pattern of support is, relatively speaking, still not very large. It represents only 1.2 percent of all R&D spending by industry, and only 6.7 percent of all R&D funds received by colleges and universities.

Table I-12 displays levels of spending by the various performers of R&D. Industry has gone from spending 68.7 percent of total national R&D funds in 1975 to about 73 percent in each of the years 1985 through 1987. In addition to accounting for virtually all of its own R&D spending, industry also consumes over half (51.9 percent) of all federal funds for R&D (see Table I-10). From all sources, industrial performance of R&D has nearly doubled in constant dollars since 1975.

Table I-13 provides a breakdown of industrial R&D spending by area. These data are not gathered in the same manner as the NSF data, and they are somewhat more dated. The top four areas of R&D spending by industry remain essentially the same as in recent years: computers is the largest area, followed by the automotive industry, pharmaceuticals, and chemicals. The sharpest one-year increases in R&D spending in 1985 came in peripheral equipment for information processing, followed by R&D by conglomerates, machine tools and industrial and mining machinery, and software services. The sharpest drops in R&D came in information processing equipment for offices, followed by textiles and apparels, and food and beverages.

D. National Patterns of R&D

Table I-10 shows national patterns of R&D spending estimated by NSF for calendar year 1987, arraying sources of funds against R&D performers. Total national expenditures for R&D in 1987 are estimated at $125.2 billion. In constant dollars this represents an 11.2 percent increase over the two-year period 1985-87.

Federal spending will account for just over $60 billion, or about 48 percent of all national R&D spending. Federal spending has also shown the largest growth (14.3 percent in constant dollars) over the past two years, among the various sectors of support. Industry is projected to spend over $61 billion, or about 49 percent of national totals, and has shown quite respectable growth in constant dollar spending (9.1 percent) over the past two years. Colleges and universities are expected to perform $11.1 billion of R&D, with 63 percent of those funds coming from the federal government, and about another quarter being supported by colleges and universities themselves. Growth in the latter figure has been slower -- 3 percent in constant dollars since 1985. Non-profit institutions provide the smallest component of national R&D spending, estimated at about $1.3 billion in 1987. This total would represent a 10 percent decrease in constant dollars in the past two years.

Table I-1. Composition of the FY 1988 Budget
(outlays in billions)

	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88
CURRENT DOLLARS				
National defense	$273.4	$282.2	$297.6	5.5%
R&D included	(35.7)	(37.7)	(41.7)	(10.6%)
Payments and grants*	508.8	520.8	534.2	2.6%
Net interest	136.0	137.5	139.0	1.1%
Undistributed offsetting receipts	-33.0	-37.1	-45.4	N/A
Other government	104.7	112.2	98.9	-11.9%
R&D included	(16.5)	(17.4)	(17.8)	(2.3%)
TOTAL OUTLAYS	$989.8	$1,015.6	$1,024.3	0.9%
R&D included	(52.1)	(55.1)	(59.5)	(8.0%)
CONSTANT FY 1982 DOLLARS				
National Defense	$242.1	$242.6	$246.9	1.8%
R&D included	(31.1)	(31.9)	(34.2)	(7.2%)
Payments and grants*	440.9	437.9	433.8	-0.9%
Net interest	117.9	115.6	113.0	-2.2%
Undistributed offsetting receipts	-29.4	-32.2	-38.4	N/A
Other government	94.6	98.4	84.1	-14.5%
R&D included	(14.7)	(15.0)	(14.8)	-1.3%
TOTAL OUTLAYS	$866.2	$862.3	$839.3	-2.7%
R&D included	(45.8)	(47.0)	(49.0)	(4.3%)

Source: Budget of the United States Government, Fiscal Year 1988.

*Payments to individuals and grants-in-aid.

Table I-2. Projections through FY 1992 in the FY 1988 Budget (in billions)

	FY 1988 Budget	FY 1989 Projected	FY 1990 Projected	FY 1991 Projected	FY 1992 Projected
CURRENT DOLLARS					
Outlays:					
National Defense	$297.6	$312.2	$330.0	$349.5	$370.9
R&D included	(41.7)	(45.7)	(42.7)	(43.3)	(44.8)
Payments and grants	534.2	562.7	589.7	619.9	649.6
Net interest	139.0	141.5	139.0	134.8	122.1
Undistributed offsetting receipts	-45.4	-45.8	-48.5	-54.0	-55.6
Other government	98.9	98.3	97.7	94.3	92.0
R&D included	(17.8)	(18.1)	(18.9)	(19.0)	(19.6)
TOTAL OUTLAYS	$1,024.3	$1,069.0	$1,107.8	$1,144.4	$1,178.9
R&D included	(59.5)	(63.8)	(61.6)	(62.3)	(64.4)
Receipts	916.6	976.2	1,048.3	1,123.2	1,191.2
Deficit (-) or Surplus (+)	-107.8	-92.8	-59.5	-21.3	+12.3

Table I-2, continued

	FY 1988 Budget	FY 1989 Projected	FY 1990 Projected	FY 1991 Projected	FY 1992 Projected
CONSTANT FY 1982 DOLLARS					
Outlays:					
National Defense	246.9	250.2	256.0	263.6	273.2
R&D included	(34.2)	(36.6)	(33.1)	(32.7)	(33.0)
Payments and grants	433.8	441.6	447.8	457.5	468.2
Net interest	113.0	111.1	105.6	99.5	88.0
Undistributed offsetting receipts	-38.4	-37.1	-38.5	-41.5	-41.2
Other government	84.1	80.8	77.8	73.0	69.6
R&D included	(14.8)	(14.3)	(14.4)	(14.1)	(14.2)
TOTAL OUTLAYS	$839.3	$846.6	$848.6	$852.2	$857.8
R&D included	(49.0)	(50.9)	(47.5)	(46.8)	(47.2)

Source: Authors' estimates based on Budget of the United States Government, Fiscal Year 1988, Historical Tables.

Table I-3. Budget Authority, Obligations and Outlays for R&D
(in millions)

	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88
CURRENT DOLLARS				
National Defense R&D				
Budget Authority	$37.6	$41.2	$48.1	16.8%
Obligations	37.1	40.9	47.6	16.5%
Outlays	36.3	38.4	42.6	10.8%
Non-Defense R&D				
Budget Authority	17.0	18.6	21.3*	14.6%*
Obligations	17.0	18.7	19.1	2.5%
Outlays	16.9	17.9	18.4	2.8%
Total R&D				
Budget Authority	54.6	59.8	69.4*	16.1%*
Obligations	54.2	59.5	66.7	12.1%
Outlays	53.1	56.3	61.0	8.3%
CONSTANT FY 1982 DOLLARS (Budget Authority only)				
National Defense R&D	$33.3	$35.4	$39.9	12.8%
Non-Defense R&D	14.8	15.7	17.4	10.6%
Total R&D	$48.1	$51.1	$57.3	12.1%

Source: OMB "Data for Special Analysis J," FY 1988, and agency supporting data. Constant dollar estimates derived from OMB fiscal year deflators for national defense R&D and all other R&D.

Table I-4. Major Components of Federal Funding for R&D*
(budget authority in billions)

	FY 1967 Actual	FY 1972 Actual	FY 1985 Actual	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget
CURRENT DOLLARS						
Defense [1]	$8.8	$9.2	$34.7	$37.6	$41.2	$48.1
Non-defense [2]	$8.3	$7.9	$17.0	$17.0	$18.6	$21.3
Space [3]	4.7	2.7	2.4	1.9	2.4	3.1
Health [4]	1.3	2.0	5.8	5.9	7.0	9.0 [7]
Energy [5]	0.6	0.6	2.5	2.4	2.2	2.0
General Science [6]	0.5	0.7	2.1	2.1	2.2	2.6
All Other	1.2	1.9	4.2	4.7	4.8	4.7
Total R&D	17.1	17.1	51.7	54.6	59.8	69.4 [7]
CONSTANT FY 1982 DOLLARS						
Defense [1]	$29.0	$22.2	$31.4	$33.3	$35.4	$39.9
Non-defense [2]	$24.5	$17.6	$15.2	$14.8	$15.7	$17.4
Space [3]	13.9	6.0	2.1	1.7	2.0	2.5
Health [4]	3.8	4.4	5.2	5.1	5.9	7.3
Energy [5]	1.8	1.3	2.2	2.1	1.9	1.7
General Science [6]	1.5	1.6	1.9	1.8	1.9	2.1
All Other	3.5	4.2	3.8	4.1	4.0	3.8
Total R&D	$53.5	$39.8	$46.6	$48.1	$51.1	$57.3

Table I-4, continued

Source: Authors' estimates based on data from OMB and agency budget justifications. Conversion constant FY 1982 dollars by authors based on OMB deflators. Columns may not add due to rounding.

*Includes conduct of R&D and R&D facilities.

[1] Includes DOD and defense activities of DOE.
[2] Includes all R&D not in defense.
[3] Reflects totals for NASA R&D less space applications and aeronautics.
[4] Includes health research in HHS, VA, Education and EPA. FY 1967 and 1972 based on OMB data for health research in all federal agencies.
[5] Includes NRC, EPA energy research, and DOE less defense activities and general science.
[6] Includes NSF and DOE general science.
[7] Includes $2.7 billion "advanced appropriation" for NIH. See Chapter 1 for details.

Table I-5. R&D by Character of Work
(budget authority in billions)

	FY 1967 Actual	FY 1972 Actual	FY 1985 Actual	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget
CURRENT DOLLARS						
Basic Research	$1.8	$2.2	$7.8	$8.2	$9.0	$10.8
Applied Research	2.9	3.6	8.7	8.2	8.8	9.4
Total Research	4.7	5.8	16.5	16.4	17.9	20.2
Development	11.8	10.7	33.4	36.7	40.1	47.2
Total conduct of R&D	16.5	16.5	49.9	53.1	58.0	67.4
R&D Facilities	0.6	0.6	1.9	1.6	1.8	2.0
TOTAL R&D	$17.1	$17.1	$51.8	$54.6	$59.8	$69.4
CONSTANT FY 1982 DOLLARS						
Basic Research	$6.4	$5.5	$7.1	$7.1	$7.7	$8.8
Applied Research	10.4	9.0	7.9	7.2	7.5	7.7
Total Research	16.8	14.5	15.0	14.3	15.2	16.5
Development	42.1	26.8	30.2	32.4	34.4	39.1
Total conduct of R&D	58.9	41.3	45.2	46.7	49.6	55.5
R&D Facilities	2.1	1.5	1.7	1.4	1.5	1.7
TOTAL R&D	$61.0	$42.8	$46.9	$48.1	$51.1	$57.3

Source: "OMB Data for Special Analysis J," as revised, and National Science Foundation, Federal Funds. Conversion to constant dollars by authors based on OMB deflators.

[1] Authors' estimates based on above sources. Basic and applied research figures adjusted to reflect reclassification of DOD research for comparability with current figures.

NOTE: FY 1988 figures include $2.7 billion "advanced appropriation" for NIH, of which approximately $1.7 billion is estimated to be basic research. See Chapter 1 for details.

Table I-6. Defense and Non-Defense R&D by Character of Work
(budget authority in millions)

	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88 Current $	% Change FY 1987-88 Constant $
Basic Research					
Defense	$960.0	$898.2	$924.6	2.9%	-0.6%
Non-Defense	7,200.7	8,141.2	9,880.8	21.4%	17.1%
Total	8,160.7	9,039.4	10,805.4	19.5%	15.3%
Applied Research					
Defense	2,521.0	2,593.0	2,756.9	6.3%	2.6%
Non-Defense	5,715.9	6,228.5	6,682.8	7.3%	3.5%
Total	8,236.9	8,821.5	9,439.7	7.0%	3.2%
Development					
Defense	33,427.0	36,750.1	43,354.1	18.0%	13.9%
Non-Defense	3,242.9	3,384.9	3,798.9	12.2%	8.3%
Total	36,669.9	40,135.0	47,153.0	17.5%	13.4%
Total Conduct of R&D					
Defense	36,908.0	40,241.3	47,035.6	16.9%	12.8%
Non-Defense	16,159.5	17,754.6	20,362.5	14.7%	10.6%
Total	53,067.5	57,995.9	$67,398.1	16.2%	12.2%

Table I-6, continued

	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88 Current $	% Change FY 1987-88 Constant $
R&D Facilities					
Defense	735.9	918.9	1,051.4	14.4%	10.4%
Non-Defense	817.3	854.5	967.6	13.2%	9.2%
Total R&D Facilities	1,553.2	1,773.4	2,019.0	13.8%	9.9%
TOTAL, R&D					
National Defense	37,643.9	41,160.2	48,087.0	16.1%	12.8%
Non-Defense	16,976.8	18,609.1	21,330.1	14.6%	10.6%
TOTAL, R&D	$54,620.7	$59,769.3	$69,417.1	16.1%	12.1%

Source: OMB "Data for Special Analysis J," FY 1988 Budget, and agency supporting data. Constant dollar data derived from OMB fiscal year deflators for national defense R&D and non-defense R&D.

NOTE: FY 1988 non-defense figures include $2.7 billion "advanced appropriation" for NIH. See Chapter 1 for details.

Table I-7. R&D in Selected Agencies
(budget authority in millions)*

	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88 Current $	% Change FY 1987-88 Constant $
DOD	$35,000.1	$38,374.5	$45,071.2	17.5%	13.4%
DOE - defense	2,643.8	2,785.7	3,015.8	8.3%	4.5%
(TOTAL Defense)	(37,643.9)	(41,160.2)	(48,087.0)	(16.8%)	(12.8%)
DOE - general science	662.9	716.8	811.7	13.2%	9.2%
DOE - energy	2,233.5	2,058.6	1,857.4	-9.8%	-13.0%
(TOTAL DOE)	(5,540.2)	(5,561.1)	(5,684.9)	(2.2%)	(-1.5%)
NASA	3,728.5	4,302.1	4,952.1	15.1%	11.0%
NSF	1,400.0	1,520.3	1,773.7	16.7%	12.5%
NIH	5,013.6	5,895.0	7,970.5 [1]	35.2% [1]	30.4% [1]
Other HHS	639.2	814.8	699.8	-14.1%	-17.2%
USDA	959.9	1,027.5	978.9	-4.7%	-8.1%
EPA	323.6	325.8	345.2	6.0%	2.2%
Education	131.2	131.9	134.5	2.0%	-1.6%
NOAA	270.1	278.2	215.3	-22.6%	-25.3%
NBS	104.9	109.3	122.6	12.2%	8.2%
USGS	219.4	208.6	213.4	2.3%	-1.3%
Bureau of Mines	78.7	73.6	70.9	-3.7%	-7.1%
All Other	1,211.3	1,146.6	1,184.1	3.3%	-0.4%
(TOTAL Non-defense)	(16,976.8)	(18,609.1)	(21,330.1)	(14.6%)	(10.6%)
Total R&D	$54,620.7	$59,769.3	$69,417.1	16.1%	12.1%

Source: "OMB Data for Special Analysis J," as revised, and agency budget justifications.

*Includes conduct of R&D and R&D facilities.

Table I-8. Conduct of Basic Research by Agency in Current Dollars
(budget authority in millions)

	FY 1982 Actual	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88 Current $	% Change FY 1987-88 Constant $
HHS	$1,954	$3,324	$3,924	$5,394 [1]	37.5% [1]	32.6%[1]
(NIH)	(1,841)	(3,108)	(3,622)	(5,127)[1]	(41.6%)[1]	(36.5%)[1]
NSF	913	1,256	1,358	1,585	16.7%	12.6%
Defense-Military	696	954	892	918	2.9%	-0.6%
Energy	779	961	1,079	1,133	5.0%	1.3%
NASA	536	919	1,018	1,017	-0.1%	-3.7%
Agriculture	334	433	460	454	-1.4%	-4.9%
Interior	74	129	122	115	-5.7%	-9.0%
Smithsonian	56	69	72	80	11.1%	7.2%
Commerce	17	26	23	24	2.1%	-1.5%
VA	13	15	16	16	4.5%	0.8%
Education	16	11	12	11	-2.6%	-6.0%
EPA	24	40	38	36	-4.0%	-7.3%
AID [2]	--	5	3	*	-84.6%	-85.2%
Other	31	22	23	22	-4.3%	-7.7%
Total, Basic Research Current Dollars	$5,440	$8,161	$9,039	$10,805 [1]	19.5%[1]	--
(Constant FY 1982 Dollars)	($5,440)	($7,123)	($7,652)	($8,822)	--	(15.3%)

Source: "OMB Data for Special Analysis J."

Columns may not add due to rounding; percentages calculated on unrounded numbers.

[1] Includes $2.7 billion "advanced appropriation" for NIH, of which approximately $1.7 billion is estimated to be basic research. See Chapter 1 for details.

[2] Reported under "Other" in 1982.

*Less than $0.5 million.

Table I-9. Estimated Support for Conduct of R&D at Colleges and Universities in Current Dollars (budget authority in millions)

	FY 1986 Actual	FY 1987 Est.	FY 1988 Budget	% Change FY 1987-88 Current $	% Change FY 1987-88 Constant $
HHS	$3,277.9	$3,937.2	$5,055.9 *	28.4%*	23.9%*
(NIH)	(3,017.9)	(3,587.1)	(4,742.6)*	(32.2%)*	(27.5%)*
NSF	999.4	1,079.9	1,259.6	16.6%	12.5%
Defense-Military	992.0	1,090.4	1,157.7	6.2%	2.5%
Agriculture	272.1	291.6	240.6	-17.5%	-20.4%
DOE	409.2	467.2	370.1	-20.8%	-23.6%
NASA	274.5	307.0	337.0	9.8%	5.9%
AID	44.1	44.9	51.0	13.6%	9.6%
EPA	54.3	61.3	64.6	5.4%	1.7%
Education	83.3	89.7	90.3	0.7%	-2.9%
Interior	32.1	22.2	24.1	8.6%	4.7%
Transportation	16.8	10.2	9.8	-3.9%	-7.2%
Commerce	56.3	50.0	35.6	-28.8%	-31.3%
Other	16.9	16.0	17.5	9.4%	5.5%
Total Current Dollars	$6,528.9	$7,467.6	$8,713.8 *	16.7% *	--
(Constant FY 1982 Dollars)	($5,701.9)	$6,326.7)	($7,120.4)	--	(12.5%)

Source: "OMB Data for Special Analysis J," as revised. Conversion to constant FY 1982 dollars by authors based on OMB deflators.

Columns may not add due to rounding; percentages calculated on unrounded numbers.

*Includes portion of "advanced appropriation" for NIH for FY 1988. *See Chapter 1 for details.*

Table I-10. National Pattern of R&D: Estimated 1987
Expenditures and Two-Year Constant Dollar Changes (1985-1987)
(dollars in millions)

Performers of R&D	Source of Funds Federal Government	Industry	Colleges & Universities	Non-profit Institutions	Total Funds for R&D
Federal Government	$15,400 9.6%	--	--	--	$ 15,400 9.6%
Industry	$31,178 17.6%	$59,872 8.1%	--	--	$ 91,050 8.2%
Colleges and Universities	$ 6,993 7.6%	$ 746 45.5%	$2,504 3.0%	$ 857 17.5%	$ 11,100 9.1%
Federally financed R&D Centers	$ 3,825 21.7%	--	--	--	$ 3,825 21.7%
Non-profit institutions	$ 2,700 13.6%	$ 730 112.8%	--	$ 395 -40.1%	$ 3,825 13.1%
Total, All Performers of R&D	$60,096 14.3%	$61,348 9.1%	$2,504 3.0%	$1,252 -10.0%	$125,200 11.2%

Source: National Science Foundation, advance data for National Patterns of Science and Technology Resources, 1987 (in preparation).

Amounts represent current operating costs based on data from performers of R&D and therefore do not correspond exactly to the figures for R&D in the budget elsewhere in this report. Capital expenditures for R&D are generally excluded.

Table I-11. National Funds for R&D by Source of Funds [1]
(in millions)

	FY 1975 Actual	FY 1980 Actual	FY 1985 Est.	FY 1986 Est.	FY 1987 Est.
CURRENT DOLLARS					
Federal Government	$18,109	$29,451	$50,915	$54,983	$60,096
Industry	15,820	30,911	54,385	58,737	61,348
Colleges and Universities	749	1,323	2,200	2,376	2,504
Non-profit institutions	535	908	1,300	1,404	1,252
Total	35,213	62,593	108,800	117,500	125,200
CONSTANT 1982 DOLLARS					
Federal Government	30,986	34,546	45,481	47,895	50,748
Industry	26,679	36,064	48,682	51,165	51,805
Colleges and Universities	1,302	1,561	1,960	2,069	2,115
Non-profit institutions	916	1,065	1,161	1,222	1,057
Total	$59,883	$73,236	$97,283	$102,350	$105,725
Total R&D, percent of GNP	2.20%	2.29%	2.72%	2.78%	2.79%

Source: National Science Foundation, advance data for National Patterns of Science and Technology Resources 1987 (in preparation).

[1] Amounts represent current R&D operating costs based on data from performers of R&D and therefore do not correspond to the figures for R&D in the budget elsewhere in this report. Capital expenditures for R&D are generally excluded.

Table I-12. National Funds for R&D by Performers of R&D[1]
(in millions)

	1975 Actual	1980 Actual	1985 Est.	1986 Est.	1987 Est.
CURRENT DOLLARS					
Federal Government	$5,354	$7,632	$13,150	$13,525	$15,400
Industry	24,187	44,505	79,500	86,225	91,050
Colleges and Universities	3,409	6,060	9,500	10,600	11,100
FFRDC's[2]	987	2,246	3,400	3,675	3,825
Non-profit institutions	1,276	2,150	3,250	3,475	3,825
Total	$35,213	$62,593	$108,800	$117,500	$125,200
CONSTANT 1982 DOLLARS					
Federal Government	$9,308	$9,006	$11,715	$11,750	$13,000
Industry	40,781	51,919	71,166	75,100	76,900
Colleges and Universities	5,927	7,151	8,463	9,250	9,375
FFRDC's[2]	1,716	2,650	3,029	3,212	3,225
Non-profit institutions	2,151	2,508	2,909	3,038	3,225
Total	$59,883	$73,235	$97,283	$102,350	$105,725

Source: National Science Foundation, advance data for National Patterns of Science and Technology Resources 1987 (in preparation).

[1] Amounts represent current R&D operating costs based on data from performers of R&D and therefore do not correspond to the figures for R&D in the budget elsewhere in this report. Capital expenditures for R&D are generally excluded.

[2] Federally Funded Research and Development Centers.

40 *Table I-13 Industry Spending*

Table I-13. Industry Spending for R&D by Business Week Groupings, 1985 (in millions)

Industry	1985	% Change from 1984
Aerospace	$2,992.2	2%
Appliances	120.6	-7%
Automotive		
cars, trucks	6,382.1	12%
parts, equipment	220.2	-4%
Building Materials	202.9	10%
Chemicals	3,648.2	0%
Conglomerates	2,356.9	42%
Containers	69.5	-5%
Drugs	3,996.1	4%
Electrical	1,613.0	-2%
Electronics	2,293.6	11%
Food and Beverage	596.2	-11%
Fuel	2,200.7	-8%
Information Processing		
computers	7,553.5	11%
office equipment	412.4	-55%
peripherals	1379.9	105%
software, services	413.8	34%
Instruments: measuring devices, controls	1,121.5	19%
Leisure Time Industries	1,302.4	10%
Machinery		
farm construction	729.3	-5%
machine tools, industrial and mining	623.1	36%
Metals and Mining	200.4	1%
Miscellaneous Manufacturing	1,544.7	7%
Oil Service and Supply	821.3	-7%
Paper	340.7	9%
Personal and Home Care Products	771.1	-8%
Semiconductors	1,164.5	18%
Steel	137.0	-8%
Telecommunications	2,925.9	5%
Textiles, Apparels	71.1	-13%
Tire, Rubber	550.8	-3%
Tobacco	21.6	2%
Total	$48,777.2	7%

Source: Based on "R&D Scoreboard, 1985" (Business Week, June 23, 1986).

NOTE: Based on SEC data for companies reporting 1985 sales of $35 million or more, and R&D expenses amounting to at least $1.0 million or 1.0 percent of sales.

Senator SARBANES. Mr. Teich, I know that the American Association for the Advancement of Science follows closely the R&D function in the Federal budget.

Do you have—does the association have—a developed position on whether there should be structural changes in R&D decisionmaking within the Federal Government? Leaving aside the question of money levels for the moment, do you have any suggestions as to how the Government ought to address these R&D decisions?

Mr. TEICH. Well, the association does not have an articulated position on that question. But I can speak to it as an individual who has the role of following the R&D budget, if you would like.

Senator SARBANES. We certainly want to hear.

Mr. TEICH. My view is—and while I recognize, and Congressman Scheuer pointed out in a discussion with Mr. Bloch a few moments ago, the need for annual accountability—I also understand the structural nature of both the executive branch and the Congress, which really divides up R&D into many different decision areas. I think some kind of more articulated structure that would provide the Congress in its budget considerations with an overview of what decisions on R&D in different places mean to one another would be an extremely important innovation in improving the way we deal with R&D in the budget.

It is the kind of function that presumably the Science Committees in the House and Senate play but only to a limited extent at present. Someone has to be able to look at the big picture and to see what the pieces mean relative to one another, not just at the end of the process, but as the process is going on.

That is one area that I think is a necessary one to be looking into.

The other has to do with the annual changes from year to year. And as I said, while I understand the importance of accountability on an annual basis and the need to adjust spending levels to changing economic conditions, at the same time the kind of budgetary ups and downs, particularly uncertainties over an extended period of time that we have experienced in the past several budget cycles are really inconsistent with the kinds of planning and program decisions that need to be made to run rational R&D programs.

And something really needs to be done to try and provide a bit more stability, if you will, for the R&D elements of the budget to allow for more rational use of resources.

It is just wasteful to deal with the uncertainty the way we have to deal.

Senator SARBANES. If the Federal Government were to put more money into nonmilitary R&D, would you have changes to recommend as to how that money is put in? Or do you think the existing system for putting in the money is adequate?

Mr. TEICH. The existing system of spending by individual agencies, each of which runs its own R&D program?

Senator SARBANES. Even more how they relate to the private sector through the grants, and so forth, and how they deal with the universities, and so on.

Mr. TEICH. Well, I think the system as we have it, in terms of the relationships among the Federal Government, private firms, universities and other R&D performing bodies is one of the most successful institutional partnerships that one can cite anywhere.

With due respect to the Japanese and their ability to make nationwide decisions with respect to industries, I think that in terms of our own R&D system, the world has a lot to envy in the way we collaborate among the sectors.

I do think there are areas in which improvements can be made. There are several signs that improvements are being made, changes are being made in the way in which the institutions of the R&D system relate to one another.

One of these has to do with the growing role of the States. That is something that has been neglected over a tremendously long period of time. The States have not played a major role in R&D in this country until recently. In fact, NSF used to tabulate in its statistical series R&D funding by States and local governments, but gave it up in about 1977 because it decided there wasn't enough there to be worth the effort.

I have been looking at what has been going on at the State level, motivated by the competitiveness, by the threat of industrial decline in some parts of the country. The States have gotten to science and technology in a very big way, and I think that is very encouraging. I think it is an asset to our R&D system to have the States involved and to recognize the importance of science and technology to their economies in the States and regions and to take pains to encourage it.

I think another thing that is very encouraging—and it is tied in with the States activities—is a growing set of relationships between industry and universities. For a long time this was nothing but talk. People made speeches about it, but we did not really see much in the way of action. But I think we are beginning to see now—and the statistics bear it our—tremendous growth in interactions between industrial firms and universities, direct interactions between industrial firms and universities. I think that can only be productive to the transfer of technology and of knowledge from basic research institutions to the institutions that put them to work for economic growth purposes.

Senator **Sarbanes**. Congressman Scheuer.

Representative **Scheuer**. Thank you, Mr. Chairman.

Thank you for your testimony, Mr. Teich. You talked about this transfer from the Federal Government to the States. Laudable as that may seem, I wonder if a good deal of that is responsible for the fact that this administration has just cut down basic research on items that to me seem clearly Federal in nature; for example, acid rain. Why should 50 States have to figure out what to do about acid rain? It is the same precipitant falling from the sky.

Groundwater research, it is easy to say turn it over to the States—and that this government has done—but wouldn't it make far more sense in many areas of research for the research to be done by the Federal Government and then disseminated to the States, rather than the 50 States, each one of them to reinvent the wheel?

Mr. **Teich**. I couldn't agree more. When I was referring to the efforts in the States and localities, I was really thinking of their support for industrial development, not for their environmental research. I think environment is one area in which this administration has cut back substantially in its research efforts.

Representative SCHEUER. Except on acid rain, where they quadrupled the research effort, and there it is only explicable in terms of not wanting to do anything about the problem itself and figuring, "Well, let's just keep researching it to death."

Let me ask you this. There are a couple of kinds of projects like the space shuttle and the supercollider that absorb massive amounts of research, even when they are civilian and not military. Does this limit the ability of the country to engage in smaller research projects that might have larger net benefits per dollar of research funds expended? Is large necessarily more cost effective? Is small frequently more productive, based on dollars expended?

Mr. TEICH. It depends on what you want to do. You cannot really build a small superconducting supercollider or a small permanent manned space station. If you want to do those things, you have to do them on a large scale. So there is a value choice that is really involved here.

I think the core, the basic essence of our fundamental research system in this country is the small, individual research grants. They have been that for at least throughout the postwar period. I think there is certainly the possibility—I don't think that we have really seen it yet, although there may be some among my colleagues who would disagree—but there is certainly the possibility that the more money that gets tied up in the large efforts, the more difficult it may be within a fixed budget for a given agency to get money for the small grants. Large projects tend to generate powerful constituencies; and small projects, small, individual researchers don't have the same concentration of power within their constituency and therefore they are at a competitive disadvantage.

Representative SCHEUER. Let me just ask you about the quality of these grants large or small. They are based now on an application for a project grant going through a peer-review system. Does that peer review bias the awarding of grants to more or less conventional projects? And should we think about some way of funding unconventional, risky projects that are sort of at the cutting edge where perhaps the consensus of the scientific community being sort of conservative might be, "Well, that's not very promising. It's too dangerous, too risky"? Is there room for unconventional, risky research projects especially in pure research?

Mr. TEICH. I think there is. I think it is more than a question of pure research and more than a question of peer review. There ought to be room for unconventional approaches and studies that are risky.

But it is more, I think, than risking the resources that is involved. Individuals who want to engage in high-risk projects, scientists, individual scientists and engineers also recognize that their career progress may be at stake. There are opportunities for getting funds, for example, through young investigator programs that provide special consideration to people who may not be established researchers, they exist on a relatively small scale compared to the overall picture, but they do exist.

So, there are some opportunities for funding for nonestablished researchers or unconventional work, but I think that the system, the competitiveness of the scientific research system itself, may tend to drive out some of this, because of scientists not wanting to risk their careers. You have to worry about being able to publish something. Publishing negative results is not very interesting; it does not get you very much in the way of recognition.

Representative SCHEUER. One last question. Mr. Teich, it looks as if for the few years ahead at least, we are all going to have to make do on less, and that includes the scientific research community, too. This is a time when it is perfectly obvious that we are operating under severe constraints. Is there anything that you can suggest that would make our scientific research community more lean and mean, more cost effective? Can you suggest any new approaches, for example, that wouldn't require a great deal of additional Federal funding? How can we do more with the funds that we have now and do what we are accomplishing now with less funds, which is a very likely prospect for the immediate future?

Mr. TEICH. It is not a cheerful prospect, I admit. I think the terms of the academic research community, to some extent the growth in industrial funding can be of assistance, although it is still a very small piece compared to the total of Federal funding. I don't have any overall unique and creative solutions to that problem, but I do think that the scientific community has shown itself to be adaptable and capable dealing with adversity and there are ways to improvise in terms of laboratory equipment and procedures and so on.

But I would think I would stop before accepting the assumption of yours on faith and ask about the——

Representative SCHEUER. It was not an assumption, it was a question.

Mr. TEICH. The assumption upon which the question was based, that there has to be less money for R&D, because I think you look on R&D as an investment in the future and you compare the value of putting money into it in comparison to other things in which the Government might put its money, then I think you can build a very strong case for not reducing R&D spending even in a time of economic stringency.

Representative SCHEUER. I quite agree.

Think you very much, Mr. Chairman.

Senator SARBANES. I think that is a very important note on which to end Mr. Teich's testimony.

You have been enormously helpful, and we appreciate it very much. Thank you, sir.

Mr. TEICH. Thank you, sir.

Senator SARBANES. We will now turn to our concluding panel. We are very pleased that two very distinguished academics are with us: Prof. Edwin Mansfield, director for the Center for Economics and Technology at the University of Pennsylvania; and Prof. Nathan Roseberg of the Economics Department of Stanford University.

Gentlemen, we have your prepared statements. We will include them in their entirety in the record. It may be helpful if you could summarize the main points. We will hear from both of you and then go to questioning. If you have not worked out an order between you on how to proceed, why don't we just do it alphabetically? Mr. Mansfield, we will start with you and then go to Mr. Rosenberg. If you would take 5 to 10 minutes each to kind of summarize your main points.

STATEMENT OF EDWIN MANSFIELD, DIRECTOR, CENTER FOR ECONOMICS AND TECHNOLOGY, AND PROFESSOR OF ECONOMICS, UNIVERSITY OF PENNSYLVANIA

Mr. **Mansfield.** All right. It is an honor to be invited to testify before this committee.

In general, American science and technology is obviously very strong, but it is well known that American technological leadership is being severely challenged in many industries, particularly by the Japanese. Although the outcome of the intense rivalry that currently exists will be determined, in part, by how quickly and economically each nation's firms can develop and commercially introduce the new products and processes that are central to success in these industries, very little systematic investigation has been undertaken to find out how much of an advantage, if any, Japan really has in this regard and to identify the factors determining whether this advantage is big or small.

The first objective of my testimony is to summarize briefly the results of a study that I carried out, financed by NSF, that provides new information on this score. Based on data obtained from a random sample of 50 Japanese and 75 American firms in chemicals, rubber, machinery, instruments, metals, and electrical equipment, there was overwhelming agreement among firms from both countries that the Japanese tend to develop and commecially introduce new products and processes more quickly than the Americans, although their advantage in this regard is not as great as is sometimes claimed. The difference may be about 6 to 18 percent, on the average. There is considerable variation among industries in this regard.

On the average, Japanese firms also develop and commecially introduce new products and processes more cheaply than American firms, using purchasing power parities. The results come out to be maybe a 20-percent differential. Again, there is variation among industries, where the big difference is in machinery and the small one is in chemicals.

To understand the factors responsible for these cost and time differentials, we must recognize that some innovations are based largely on external technology, technology developed outside the innovative firm, while others are based on internal technology, technology developed within the innovative firm.

To see whether these cost and time differentials depended on the type of innovation, we picked a random sample of 60 American and Japanese firms in these same industries that were matched pairs. We got detailed data from each of these firms as to how much their new products during 1975 to 1985 cost and how long they took to develop and commercialize. The results indicated that there was no statistically significant difference between the Japanese and Americans for innovations based on internal technology, but a big difference for innovations based on external technology.

Many innovations based on external technology are new products that imitate others in important respects. The fact that American firms spend so much more on marketing startup than the Japanese is an important element here and one that is very seldom alluded to or recognized.

The relatively higher commercialization costs for innovations based on external technology in the United States than in Japan seems to have been due, in part, to the fact that the Japanese in carrying out such innovations have been more likely than the Americans to have made significant technical adaptations of the imitated product or to reduce its production costs substantially. The Americans, on the other hand, have been more inclined than the Japanese to invest heavily in marketing startup costs in an effort to position such innovations optimally in the market, the emphasis being more on marketing strategies than on technical performance and production costs. Naturally, this has resulted in relatively higher commercialization costs for such innovations in the United States.

Based on relatively crude econometric models, our results suggest that American firms have obtained higher returns from basic research than the Japanese, whereas the Japanese have obtained much higher returns from applied R&D than the Americans.

The high estimated rate of return from applied R&D in Japan may be attributable, in considerable part, to Japan's being able to draw at relatively small cost on a rich stock of foreign technology that was more advanced than its own as well as to Japan's relatively small percentage of industrial R&D financed by the Government and going largely for noncommercial purposes. Also, it may have been due partly to their emphasis on process rather than product technology.

As for the difference between Japan and the United States in the returns from basic research, a lot of it has to do with the fact that the Japanese universities are not well integrated with industry and that there are problems within the Japanese university system. That we can discuss later, if you like.

Since data on total R&D expenditures, while useful, are difficult to interpret because R&D projects are so heterogeneous, we collected data concerning the composition of the R&D expenditures from a carefully selected sample of Japanese and American firms. Particularly striking is the difference between Japanese and American firms in their allocation of R&D resources between projects aimed at improved product technology and those aimed at improved process technology.

These results shed new light on a major issue concerning industrial R&D in the United States. Many observers have criticized American industry for neglecting process innovation. As the President's Commission on Industrial Competitiveness put it, it does us little good to design state-of-the-art products if within a short time our foreign competitors can manufacture them more cheaply. Contrary to common impressions, there is no evidence that we have found that American industry has increased the proportion of their R&D expenditures devoted to new and improved processes. In terms of the allocation of their R&D funds, American firms do not seem to have put more emphasis on processes, despite this criticism.

While the American response to the technological challenge from the Japanese and others must come in large part from American firms and research organizations, this does not mean, of course, that the Government has no important role to play.

Based on the available studies, governments seem to be most successful in stimulating civilian technology when they emphasize relatively broad policies rather than attempting to make detailed decisions concerning which specific designs and types of commerical products should be developed at what pace.

Because of the inherent difficulties in measuring and forecasting the social benefits from various kinds of R&D as well as other factors, it is not easy to weigh the costs and benefits of various actions that the Government might take. The following three suggestions might be considered, although it should be recognized that they are based on very limited evidence:

First, despite the fact that the United States cannot expect to appropriate all or most of the benefits, the little available evidence seems to suggest that an enhanced public investment in basic research might have a high economic payoff. The social rate of return from basic research seems to have been relatively high, based both on the econometric results cited above and on the preliminary results in the study I am currently carrying out which uses detailed data obtained directly from firms.

Second, to help American firms become more adept as imitators, government agencies might look into the potential benefits of further programs supporting, evaluating, and coordinating information-gathering activities regarding foreign technologies.

Third, to the extent that there has been an underinvestment in process innovation, agencies like the National Science Foundation might consider additional support for university research related to process technologies. And the Department of Defense, which as helped to develop advanced manufacturing technologies and has promoted their applications in particular industries, might consider doing more to transfer what it has learned to civilian industry in general.

Than you.

Senator **Sarbanes**. Thank you very much, sir. That was very helpful.

[The prepared statement of Mr. Mansfield follows:]

PREPARED STATEMENT OF EDWIN MANSFIELD

It is an honor to have been invited to testify before this committee, which is reviewing the current state of research and development in the United States and exploring options for improving the federal government's policies and programs in these areas. In general, American science and technology is strong, but, as is well known, American technological leadership is being severely challenged in many industries, particularly by the Japanese. Although the outcome of the intense rivalry that currently exists between Japan and the United States in high-technology industries (like computers, electronics, and biotechnology) will be determined in part by how quickly and economically each nation's firms can develop and commercially introduce the new products and processes that are central to success in these industries, very little systematic investigation has been undertaken to find out how much of an advantage, if any, Japan has in this regard, and to identify the factors determining whether this advantage is big or small. My first objective in this testimony is to summarize briefly the results of a two-year study that I have carried out, financed by the National Science Foundation, which provides new information on this score.

Based on data obtained from a random sample of 50 Japanese and 75 American firms in the chemical (including pharmaceuticals), rubber, machinery (including computers), instruments, metals, and electrical equipment industries,[1] there was overwhelming agreement among firms from both countries that the Japanese tend to develop and commercially introduce new products and processes more quickly than the Americans, although their advantage in this respect is not as great as is sometimes claimed. Averaged over all industries, the time differential was about 18 percent, according to the Japanese data, or 6 percent, according to the American data. However, the picture varies from industry to industry. In some industries, like machinery, both the Japanese and American data indicate that there was a substantial differential. In other industries, like instruments, the Japanese data indicate that there was a substantial differential, whereas the American data do not. In still other industries, notably chemicals, both the Japanese and American data indicate that there was no large differential.

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[1] The members of this sample account for about one-quarter of all R and D carried out in these industries in both countries. See E. Mansfield, "The Speed and Cost of Industrial Innovation in Japan and the United States: External vs. Internal Technology," paper to be presented to the 1987 annual meetings of the American Economic Association.

On the average, Japanese firms also developed and commercially introduced new products and processes more cheaply than American firms. Averaged over all industries, the resource cost differential was 23 percent, according to the Japanese data, or 10 percent, according to the American data. Here too, the situation varies from industry to industry. For example, in machinery and instruments, based on both the Japanese and American data, the cost differential seemed substantial; in chemicals, on the other hand, the American data do not indicate that any substantial differential existed.

To understand the factors responsible for these cost and time differentials, we must recognise that some innovations are based largely on external technology (i.e., technology developed outside the innovating firm) while others are based largely on internal technology (i.e., technology developed within the innovating firm). To see whether these cost and time differentials depend on whether innovations are based on internal or external technology, we picked a random sample of 60 major Japanese and American firms in the chemical (defined broadly to include pharmaceuticals and petroleum), machinery (including computer), electrical equipment, and instruments industries. The sample is composed of 30 matched pairs, where each pair consists of an American and Japanese firm of roughly comparable size in the same industry. Every firm indicated how much time and money it devoted, on the average, to the development and commercialization of each of the new products it introduced during 1975-85, depending on whether the product was based on external or internal technology. According to expert opinion, the new products introduced by each pair of firms were reasonably comparable. Since the Japanese cost figures were converted to dollars on the basis of purchasing power parities for resources used in the innovation process, they, like the figures in the previous paragraph, indicate how much (approximately) the resources used in Japan would have cost in the United States.

Like the estimates obtained from the 125-firm sample described above, the results indicate that the Japanese tend to have cost and time advantages over U.S. firms. However, these advantages seem to be confined to innovations based on external technology (where the cost and time differentials are greater than those indicated above). Among innovations based on internal technology, there seems to be no significant difference in average cost or time between Japan and the United States.

American firms take almost as long, and spend almost as much money, to carry out an innovation based on external technology as one based on internal technology. In the development part of the innovation process (beginning at the start of R and D and ending when the product is developed), an American innovation based on external technology takes less time and money than one based on internal technology; but in the commercialization part (beginning when the product is developed and ending when it is first introduced commercially), the time and cost is at least as great as one based on internal technology.

In Japan, on the other hand, firms take about 25 percent less time, and spend about 50 percent less money, to carry out an innovation based on external technology than one based on internal technology. Moreover, this is true in all industries included in my study. The contrast between Japanese and American firms in the commercialization part of the innovation process is particularly striking. Whereas in the United States the commercialization of an innovation based on external technology takes more time and about as much money as the commercialization of one based on internal technology, in Japan it takes about 10 percent less time and over 50 percent less money than the commercialization of an internal-technology-based innovation.

Many innovations based on external technology are new products that imitate others in important respects. The relatively higher commercialization cost for innovations based on external technology in the United States than in Japan seems to have been due in part to the fact that the Japanese, in carrying out such innovations, have been more likely than the Americans to make significant technical adaptations of the imitated product and/or to reduce its production costs substantially. The Americans have been more inclined than the Japanese to invest heavily in marketing startup costs in an effort to position such innovations optimally in the market, the emphasis being more on marketing strategies than on technical performance and production cost. Naturally, this has resulted in relatively high commercialization costs for such innovations in the United States.

Based on relatively crude econometric models, my results suggest that American firms have obtained higher returns from basic research than the Japanese, whereas the Japanese firms have obtained much higher returns from applied R and D than the Americans.[2] The high estimated rate of return from applied R and D in Japan may be attributable in considerable part to Japan's being able to draw at relatively small cost on a rich stock of foreign technology that was more advanced than its own, as well as to Japan's relatively small percentage of industrial R and D financed by the government (and going largely for noncommercial purposes). Also, it may have been due partly to their emphasis on process rather than product technology (discussed below). The apparently low rate of return from basic research in Japan may reflect differences between the two countries in the extent of the external benefits to industrial basic research from university research. In the United States, there often have been close working relationships between basic researchers in industry and their colleagues in the universities. In Japan, university research seems to have played a lesser role (and seems to have been less highly regarded) than in the United States.

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[2] E. Mansfield, "Industrial R and D in Japan and the United States: A Comparative Study," American Economic Review, forthcoming.

If we compare the official data in both countries, the R and D intensity of manufacturing firms has increased more rapidly in Japan than in the United States, which is not surprising, given our finding that the rate of return from applied R and D has been higher there than here. In 1986, company-financed R and D expenditures in manufacturing were about 2.7 percent of sales in Japan, in comparison with about 2.8 percent in 1985 in the United States. In 1970, the corresponding figures were 1.3 percent for Japan and 2.2 percent for the United States. In all industries other than machinery, instruments, paper, and petroleum, Japan has narrowed the gap substantially. In some industries (food, textiles, metals, and rubber) Japan now leads; in other industries (paper, petroleum, machinery, and instruments) the United States now leads; and in the rest there is a relatively small difference in R and D intensity.[3]

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[3] The Japanese data were provided by Gary Saxonhouse of the University of Michigan; the U.S. data were provided by Melissa Pollak of the National Science Foundation. They are the latest available figures. Note that government-financed R and D expenditures, which are much larger in the United States than in Japan, are excluded in these figures.

Since data on total R and D expenditures, while useful, are difficult to interpret because R and D projects are so heterogeneous, we collected data concerning the composition of their R and D expenditures from a carefully selected sample of Japanese and American firms. Fifty Japanese firms were chosen at random in the chemical, electrical equipment, instrument, machinery, rubber, and metals industries, and for each Japanese firm we picked at random an American firm of the same industry and approximate size. The firms in our sample carry out about 25 percent of the R and D in each country in these industries. Based on detailed information obtained from each of these 100 firms (50 matched pairs), the Japanese seem to devote about as large a percentage of their R and D expenditures to relatively risky and long-term projects as do American firms. This differs greatly from the early 1970s, when Peck and Tamura characterized Japanese industrial R and D as composed very largely of "low-risk and short-term projects." Nonetheless, it would be a mistake to think that Japanese and American industrial R and D have become essentially the same. Whereas American firms report that almost half of their R and D expenditures are going for projects aimed at entirely new products and processes, Japanese firms report that only about a third of their R and D expenditures go for this purpose. (Outside the chemical industry, where there is little difference in this regard, the gap is even wider.) Of course, this is in accord with a great deal of anecdotal information to the effect that the Japanese devote more of their R and D resources to the improvement and adaptation of existing products and processes (rather than to the development of entirely new products and processes) than do American firms.

Even more striking is the difference between Japanese and American firms in their allocation of R and D resources between projects aimed at improved product technology and projects aimed at improved process technology. The American firms in our sample devote about two-thirds of their R and D expenditures to improved product technology (new products and product changes) and about one-third to improved process technology (new processes and process changes). Among the Japanese firms, on the other hand, the proportions are reversed, two-thirds going for improved process technology and one-third going for improved product technology.

These results shed new light on a major issue concerning industrial R and D in the United States. Many observers have criticized American industry for neglecting process innovation. As the President's Commission on Industrial Competitiveness puts it, "It does us little good to design state-of-the-art products, if within a short time our foreign competitors can manufacture them more cheaply."[4] Contrary to the common impression that U.S. firms have in recent years begun to react to such criticism by paying more attention to process innovation than in the past, our results do not indicate that there was any perceptible increase between 1976 and 1985 in the proportion of their R and D expenditures devoted to new or improved processes. Thus, in terms of the allocation of their R and D funds, American firms do not seem to have put more emphasis on processes, despite this criticism.

At least three conclusions seem to follow from the studies described above. First, with respect to the differences between the two countries in innovation cost and time, the situation is much more varied and complex than is generally portrayed by the largely anecdotal accounts that have begun to appear. Whereas the Japanese have substantial advantages in this regard in some industries (notably machinery), they do not seem to have any substantial advantage in others (notably chemicals). Whereas they have very great advantages in carrying out innovations based on external technology, they do not seem to have any in carrying out innovations based on internal technology.

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[4] President's Commission on International Competitiveness, Global Competition: The New Reality, Washington, D.C.: U.S. Government Printing Office, 1985, p. 20.

Second, a large part of America's problem in this regard seems to be due to its apparent inability to match the Japanese as quick and effective users of external technology. As Harvey Brooks has warned, "the United States, so long accustomed to leading the world, may have lost the art of creative imitation. . ."[5] This is not to deny that part of the Japanese advantage may be due to factors like their propensity to overlap various stages of the innovation process, their subcontractor network, and their fewer organizational barriers and better communication between functional departments of firms. But the fact that the Japanese advantage tends to be limited to innovations based on external technology suggests that it is in this area that many central problems lie.

Third, our results, which are subject to many limitations detailed elsewhere, support the contention that applied R and D in Japan has yielded a handsome return, higher than in the United States. In large part, this can be explained by Japan's greater emphasis on commercial (rather than government-financed) projects, by its being able to obtain Western technology that was more advanced than its own, and which could be adapted and improved at relatively low cost, and by its emphasis on process technology, which according to many experts has tended to be neglected in the United States. On the other hand, there is no evidence that the rate of return from basic research has been relatively high in Japan. Apparently, the Japanese advantage has been confined largely to applied R and D, particularly R and D concerned with the adaptation and improvement of existing technology.

While the American response to the technological challenge from the Japanese and others must come, in large part, from American firms and research organizations, this does not mean that the government has no important role to play. Based on the available studies, governments seem to be most successful in stimulating civilian technology when they emphasize relatively broad policies rather than attempting to make detailed decisions concerning which specific designs and types of commercial products should be developed and at what pace. There is little evidence that attempts by government agencies to assume the entrepreneurial role or to regulate in detail the inflow, outflow, and application of industrial technology have been very successful, with the possible exception of Japan (about which there is considerable controversy). On the other hand, policies which are widely regarded as having been important in promoting technological change and productivity growth include those designed to promote the quality and extent of education in science, engineering, and management, to build the vigor of competition among the nation's firms, to support fundamental research, and to attain reasonably full employment with a reasonably stable price level.[6]

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[5] H. Brooks, Testimony before House Subcommittee on Science, Research and Technology, Japanese Technological Advances and Possible United States Responses Using Research Joint Ventures, 98th Congress, first session, June 29-30, 1983, p. 17.

More specifically, the results of the above and related studies, while subject to a variety of limitations discussed in the articles cited, suggest the following three points. First, despite the fact that the United States cannot expect to appropriate all or most of the benefits, the little available evidence seems to suggest that an enhanced public investment in basic research might have a high economic payoff. The social rate of return from basic research seems to have been relatively high, based both on the econometric results cited above and on the preliminary results of a study I am currently carrying out, which uses detailed data obtained directly from firms. Second, to help American firms become more adept imitators, government agencies might look into the potential benefits of further programs supporting information-gathering regarding foreign technologies. Third, to the extent that there has been an under-investment in process innovation, agencies like the National Science Foundation might consider additional support for university research related to process technologies, and the Department of Defense and NASA, which have helped to develop advanced manufacturing technologies and have promoted their application in particular industries, might consider doing more to transfer what they have learned to civilian industry in general.[7]

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[6] For further discussion, see E. Mansfield et al., *Technology Transfer, Productivity, and Economic Policy*, New York: W.W. Norton, 1982; and E. Mansfield, "Federal Support of R and D Activities in the Private Sector," in *Priorities and Efficiency in Federal Research and Development*, Joint Economic Committee of Congress, October 29, 1976.

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[7] For the results of a recent study of industrial robots, a major process innovation, see E. Mansfield, "The Diffusion of Industrial Robots in Japan and the United States," Center for Economics and Technology, University of Pennsylvania, 1987; and "Firm Growth, Innovation, and R and D in Robotics: Japan and the United States," Symposium on Research and Development, Industrial Change, and Economic Policy, University of Karlstad, Sweden, 1987.

Senator SARBANES. Professor Rosenberg, please proceed.

STATEMENT OF NATHAN ROSENBERG, PROFESSOR OF ECONOMICS, STANFORD UNIVERSITY

Mr. ROSENBERG. Thank you, Mr. Chairman. It is a great pleasure to have to opportunity to express my views before this committee.

In my statement, in my prepared statement, I have addressed the question of why the United States has been having so must difficulty in recent years in converting its great basic research capabilities into commerically successful products and processes.

The short answer, on which I elaborate in the prepared statement, the short answer is that the capabilities required for scientific leadership are very different from the capabilities required for exploiting new technologies that are generated by the scientific capabilities. It is possible for a country to excel at both, but there is nothing intrinsic in scientific competence that guarantees a high degree of commercial competence.

Furthermore, a number of forces at work in the world economy in recent years have been assuring a very rapid international transfer of new technologies, regardless of where they were first developed. The multinational firm is itself an important institution for bringing about that rapid movement of new technology.

This greater international mobility of technology is further strengthening the advantages of countries that have the downstream commerical skills as opposed to countries with the upstream scientific research capabilities. Great Britain's economic performance in the years since the Second World War demonstrates, it seems to me, the insufficiency of high-quality science when it is not associated with the complementary engineering and commercial skills and when the economic environment fails to offer higher rewards to technological innovators.

For many years, Great Britain received more Nobel Prizes in science than America on a per capita basis. We have been getting about three times as many as they have, but with about four times the population. But there is very little evidence that Britain has been able to turn this brilliant scientific capability into economic advantage.

Japan, on the other hand, has received very few, just a small handful, of Nobel science prizes. Nevertheless, it is hard to believe that this has been a major economic handicap to the Japanese economy in the past. It is almost difficult to believe that there have been any handicaps, looking at their performance.

The Japanese experience demonstrates the great possibilities for economic growth based upon a systematic transfer and exploitation of foreign technologies. It seems obvious from the Japanese experience, that given the appropriate engineering and organizational skills, a high degree of economic competitiveness can be obtained by drawing upon more advanced technologies that are available abroad and that are the product of scientific research conducted abroad.

It is, to put it the other way around, easy to exaggerate the purely economic significance of a first-rate domestic scientific research capability when it does not exist together with these complementary downstream skills that are required for the commercialization process.

To be more precise, such scientific capabilities are certainly not a sufficient condition for economic competitiveness and growth. They are almost certainly becoming a more frequent necessary condition if only because earlier access to new research findings can often be translated into a leadtime over one's competitors that may be highly advantageous. However, I have to admit how impressed I am with the number of instances where in the recent past it has not even been a necessary condition for the Japanese.

Now, all of this should not be totally surprising. The fruits of purely scientific research have always been highly portable. What I am now suggesting is that events in recent decades are rendering the findings of technological innovation highly portable internationally as well, at least under the right set of circumstances in the recipient countries.

By the right set of circumstances, I mean the cluster of capabilities associated with the ability to commercialize new products or processes. That is, again, the skills that lie further downstream from the purely scientific ones. At the macroeconomic level, I mean a stable economic environment that is conducive to investment activities and especially to the willingness in industry to make decisions on the basis of long-time situations.

These conditions have deteriorated drastically in recent years in America and in ways that I think have very direct consequences for our ability to exploit the findings of scientific research. In a variety of ways and for a variety of reasons, the American economy in recent years has been generating low rates of net savings and capital formation, rates that are in fact far lower than those of our major overseas competitors.

Let me cite some numbers here. From an annual average of about 7 percent of GNP in the 1950's—and we're talking about net savings figures here—from an annual average of almost 7 percent of GNP in the 1950's and about 7.5 percent in the 1960's, net savings declined to barely 6 percent in the 1970's and then declined much more sharply in the 1980's.

Between 1982 and 1986—I have summarized these data in a table in the back of my prepared statement—between 1982 and 1986 net savings in America averaged 2.3 percent of gross national product, and in 1986 it was a mere 1.9 percent.

Those figures, I think, tell a very important story. That is most emphatically no way to run an expanding industrial economy in a highly competitive world.

The Japanese net saving rate, by the way, has also declined in the 1980's, but it has declined to over 17 percent, from around 20 percent or so.

Now, a high rate of savings translates into a low cost of capital. Low cost of capital, in turn, translates into longer time horizons. Conversely, low rates of saving translate into a high cost of capital and slower growth in labor productivity.

In very considerable measure, in talking about international competitiveness, improving labor productivity is a matter of equipping workers with an expanding stock of machinery and equipment, and of course when the labor force itself is growing very rapidly as it has—and this is a very important point, I think, in considering American competitiveness, which is perhaps neglected—when the labor force is growing rapidly, as rapidly as it has been growing—it grew by 20 million in the 1970's alone, it grew by about—I have the exact figures in the prepared statement. But in one decade our labor force grew by about 20 million workers. When that is happening, then high rates of capital formation become even more important in providing a basis for continued productivity improvement.

There is a high correlation internationally between countries' growth in labor productivity and the growth in what economists call its capital-labor ratio. In these respects, the comparative strength of the American economy has deteriorated rapidly over the past 20 years or so. Whereas the capital-labor ratio grew by about 3 percent per year between 1948 and 1973, after 1973 it slowed to an annual growth rate of less than 2 percent a year.

And in very sharp contrast, the annual amount of fixed investment per manufacturing worker in Japan is more than twice as high as in America, and that difference is growing even wider. That seems to me to be an essential part of the story in talking about the deteriorating international competitiveness.

In the context of rapid technological change and more especially the rapid international diffusion of technology, the implications of these trends become even more serious. The cost of capital shapes the willingness to invest resources in the development of new technological possibilities opened up by scientific research. It subsequently determines the speed with which such new technologies will be embodied in new forms of machinery and equipment and the speed and extent to which firms will ultimately adopt and exploit these new technologies, and it also determines the cost of capital and the ability to supply a rapidly expanding labor force with the equipment needed to raise productivity and to maintain competitiveness.

If I could take just 2 or 3 more minutes to say a little bit more about the development component of R&D. A great scientific breakthrough is usually very remote from useful applications of that breakthrough, if indeed useful applications ever occur. Consider the great excitement all over the world concerning the remarkable breakthroughs with respect to superconductivity. And by the way, this morning, this very morning's newspaper has yet another statement of another one of these breakthroughs.

From a scientific point of view, that excitement is very well justified. In terms of its eventual economic impact, the excitement may also be justified. But it may well be a matter of decades before the scientific breakthrough can be translated into such things as magnetically levitated trains and the transmission of electricity without loss, to say nothing of the storage of electricity.

Designing new products that exploit new knowledge of high-temperature superconductors and then designing and making the technology that can produce these new products, these are extraordinarily difficult, time-consuming, and expensive activities. Such development includes the designing of new products, testing and evaluating their performance, inventing and designing new and appropriate manufacturing processes, and so on. In addition, it involves a process of endless minor modification and small improvements, each of which will bring about some slight reduction in cost or improvement in performance.

The cumulative effects of such small improvements may be immense, as when the semiconductor industry moved through a multitude of very small steps, as it has, from a single transistor on a chip up to a million such components.

Now, these development activities are not very exciting, especially considered from the perspective of academic scientists. They are activities that do not win Nobel Prizes, nor for the most part do they even win recognition of the Patent Office, and the low visibility may account for the very limited awareness of their economic importance.

In spite of the fact that development accounts for more than two-thirds of all R&D expenditures, nevertheless, poor performance at various stages of the development process can easily be commercially fatal to economies that are at the same time highly successful at research, particularly basic research. And impatience or low esteem attached to working at the finer details of product design or insufficient attention to the organization and flow of work in the factory floor, these things can be commercially fatal. It can readily translate into final products of inferior design, lower quality, and poor reliability.

It can also translate into higher costs and a slower product development cycle, so that new or improved products may eventually achieve their first or their greatest commercial exploitation in countries that neither created them nor perform the antecedent research that made the development possible.

Now, that is, of course, intended as more than just idle rumination. There is an accumulation of evidence, some of it collected by Professor Mansfield, that many Japanese successes in recent years owe a great deal to the stronger incentivies, to the higher priority, to the greater success that Japanese manufacturing firms attach to these downstream development activities.

The Japanese have on numerous occasions been the leader in the commercialization of new products in spite of the fact that the new product or some essential component was developed elsewhere. The videocassette recorder is currently one of Japan's largest export items, recently accounting for almost $6 billion per year in export earnings. Although the earliest conception and first development attemps were American, Japanese engineering, design, and manufacturing skills were responsible for solving many of the problems that needed to be overcome before commercialization was possible.

Let me stop at this point.

Senator **Sarbanes**. Thank you very much.

[The prepared statement of Mr. Rosenberg, together with an attached table, follows:]

PREPARED STATEMENT OF NATHAN ROSENBERG

I

The following discussion is intended to address this committee's concern with "U.S. performance in translating the results of basic research into usable products and processes compared to that of Japan and Europe."

In order to evaluate American performance and, eventually, to devise ways of improving that performance, it is necessary to consider how new findings in basic research are connected to a "downstream" flow of usable products and processes. Those connections are much more complex than is generally realized.

A great scientific breakthrough is usually very remote from useful applications of that breakthrough, if indeed useful applications *ever* occur. Consider the great excitement all over the world concerning the remarkable breakthroughs with respect to superconductivity. From a scientific point of view, the excitement is well justified. In terms of its *eventual* economic impact, the excitement may also be justified. But it may well be a matter of decades before this scientific breakthrough can be translated into magnetically-levitated trains and the transmission of electricity without loss, to say nothing of the storage of electricity. Designing new products that exploit new knowledge of high-temperature superconductors, and then designing and making the technology that can produce these new products, are extraordinarily difficult, time-consuming and expensive activities. Such activities fall under the category of Development rather than Research. Development covers a wide range of activities that vary very much from one industry to another. It generally includes the designing of new products, testing and evaluating their performance (which in some industries may involve the building and testing of prototypes, or experimentation with pilot plants), and inventing and designing new and appropriate manufacturing processes. In addition it involves a process of endless minor modifications and small improvements, each of which will bring about some slight reduction in cost or improvement in performance (often including the achievement of greater reliability). The cumulative effects of such small improvements may be immense, as when the semiconductor industry moves, through a multitude of small steps, from a single transistor on a chip to a million such components.

These Development activities have no single, well-defined terminus. They do not end when a new or improved product is brought to market. Quite the contrary. A continual stream of small improvements is often the essence of success in the competitive process. In industries involving complex technologies such as telecommunications, aircraft, electrical and non-electrical machinery, chemicals and allied products, automobiles and scientific instruments, Development is a never-ending activity. It is characteristic of these activities that information from marketing needs to be fed back to product design, and that specialists responsible for product design need to interact frequently with specialists responsible for manufacturing processes. Slight alterations in product design that increase its attractiveness to consumers or that enable engineers to eliminate or to simplify a step in the manufacturing sequence, may be decisive in determining commercial success or failure in bringing new products, exploiting earlier research findings, to market.

These are not very exciting activities, especially considered from the perspective of academic scientists. They are activities that do not win Nobel Prizes; nor, for the most part, do they even win recognition at the Patent Office. This low visibility may partly account for the very limited public awareness of their economic importance, in spite of the fact that Development accounts for more than two-thirds of all R and D expenditures. Nevertheless, poor performance at various stages of the Development process can easily be commercially fatal to economies that are highly successful at Research. An impatience with, or a lower esteem attached to working out the finer details of product design, or insufficient attention to the precise organization and flow of work on the factory floor, can be commercially fatal. It can readily translate into final products of inferior design, lower quality and poor reliability. It can also translate into higher cost and a slower product development cycle so that new or improved products may eventually achieve first (or greatest) commercial exploitation in countries that neither created them nor performed the antecedent research that made their development possible.

This is, of course, intended as more than just idle rumination. There is an accumulation of evidence that many Japanese successes in recent years owe a great deal to the stronger incentives and higher priority that Japanese manufacturing firms attach to these "downstream" Development activities.[1]

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[1] See Masahiko Aoki and Nathan Rosenberg, "The Japanese Firm as an Innovating Institution," unpublished manuscript presented at the Tokyo meetings of the International Economic Association, Tokyo, September

The Japanese have, on numerous occasions, been the leaders in the commercialization of new products, in spite of the fact that the new product, or some essential component, was invented elsewhere. Thus, although the U.S. pioneered at both the scientific and technological levels in the sequence of events that led to the invention of the transistor and integrated circuit, Japan was the first country to succeed in the large-scale commercialization of transistor technology for radio and she simply obliterated America's earlier dominance of color television. Similarly, in robotics, where past American leadership was conspicuous, Japan by 1984 was actually employing more than 4 times as many industrial robots as the U.S. Japanese successes in higher-quality and design improvements over a wide range of products, such as compact automobiles and consumer electronics, are too highly visible even to require comment. The video-cassette recorder is currently one of Japan's largest export items, recently accounting for almost $6 billion per year in export earnings. Although the earliest conception and first development attempts were American, Japanese engineering, design and manufacturing skills were responsible for solving many of the problems that needed to be overcome before commercialization was possible.

Japanese firms have developed impressive capabilities at these "downstream" Development activities that often more than offset the American advantages at the earlier research stages. The incentive structure of the Japanese firm, especially where it includes long-term, stable employment relationships and bonus payments geared to

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productivity improvements, seems effectively devised for mobilizing the energies of all employees in the cause of small, incremental improvements. The devolution of some degree of autonomy and decision-making responsibility down to the lowest blue collar levels encourages initiatives in many ways that contribute to the flow of such improvements. The Japanese firm would appear to make more systematic use of its engineering skills throughout the entire sequence of Development activities associated with the introduction of new products, including the most "grubby" aspects of the eventual manufacturing process. Information flows among specialists with different but related responsibilities are extremely smooth and effective, reflecting not only the incentive structure of the organization but a deliberate policy of personnel rotation to familiarize specialists with the larger context of the total flow of work within the enterprise.

These activities are not well appreciated when, as is commonly the case, Development is thought of as the *application* of scientific knowledge.[2] Development in fact incorporates knowledge from many sources. Even in those instances in which new scientific knowledge *does* provide the initial stimulus for a new product, the subsequent Development process will draw upon a wide variety of sources, the most common of which is likely to be the existing stock of "in-house" engineering knowledge. Organizational structures and incentive systems that can exploit these sources effectively will have a strong economic advantage over competitors who cannot do so, even if these competitors have a superior research capability. If these Development capabilities are sufficiently strong, the resulting shorter product development cycle may even make it possible to reach the market with a new product more quickly than firms from the country that performed the original scientific and engineering research. Indeed, this is probably already happening.

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[2] The NSF defines Development as "...the systematic use of knowledge or understanding *gained from research*, directed toward the production of materials, device systems or methods, including design and development or prototypes and processes." NSF, *Science Indicators 1985*, p. 221 (my italics)

II

The burden of my comments so far has pointed to the critical importance of downstream Development capabilities in determining whether a country can exploit its purely scientific strengths. The ability to translate research capabilities into commercial advantage has been further diminished - or at least complicated - by the fact that new technologies can be more readily transferred across international boundary lines than was the case a few decades ago.

There are a number of reasons for this. A main reason has to do with the specific characteristics of some of the new technologies that have become available since the Second World War. New techniques of transportation and communication - the jet aircraft, telecommunications, the computer - effectively guarantee that, whatever country may have been the first to introduce a new technology, it will soon be made available to other countries. At least as far as mere access to new knowledge is concerned, the specific details of, say, a major new product design can be transmitted instantly to any part of the world. In addition, increasingly sophisticated computer-aided manufacturing systems are making it possible to transfer much of the required manufacturing capabilities of a widening range of products very rapidly. Moreover, the multinational firm, and its growing importance on a global scale, is an excellent organizational device for carrying out these technology transfers. In fact, American multinationals are not only conducting more of their manufacturing abroad; for a variety of reasons, including relative costs and the nature of government regulations, an increasing proportion of their R&D activity is being conducted abroad (some of these trends are most apparent in the pharmaceutical industry[3]). It is symptomatic of the internationalization of the research process that the Nobel Prize in Physics in 1986 was won by two German scientists working in Switzerland for an American firm - IBM! Furthermore, the great increase in Development costs in such sectors as aircraft and telecommunications has led to a systematic search for overseas partners in joint venture arrangements. While these joint ventures do indeed offer the prospect of a sharing of high development costs as well as other possible commercial benefits, they also assure the even more rapid international diffusion of new technologies.

This rapid international transfer of new technologies has an important implication for our present concerns: It further reduces the purely economic advantages that once accrued to American firms because of this country's extensive and splendid scientific research capabilities. Although economic benefits will surely continue to flow from the conduct of scientific research, it is becoming less likely that these benefits will necessarily flow in the form of competitive economic advantages *to the country conducting such research*. Whether or not it will do so will depend to an increasing degree on the country's "downstream" Development capabilities.

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[3] Ed Mansfield, "R&D and Innovation; Some Empirical Findings, " in Zvi Griliches (ed.) *R&D, Patents, and Productivity*, National Bureau of Economic Research, published by University of Chicago Press, 1984, pp. 134-141.

A comparison of the recent experiences of Great Britain and Japan is appropriate here. Great Britain's economic performance in the years since the Second World War demonstrates the insufficiency of high quality science when it is not associated with the complementary engineering and managerial skills, and when the economic environment fails to offer high rewards to technological innovators or to the adopters of newly-available technologies. For many years Great Britain received more Nobel Prizes in science than America on a per capita basis, but there is little evidence of that country turning their brilliant scientific capability into economic advantage.[4] Japan, on the other hand, has received very few Nobel Science Prizes. Indeed, Japan has received only a very small fraction of the number of Nobel Science Prizes received by a single British institution - the Cavendish Lab. Nevertheless, it is hard to believe that this has been a major economic handicap to the Japanese economy in the past! Rather, the Japanese experience forcefully demonstrates the great possibilities for economic growth based upon the systematic transfer and exploitation of foreign technologies.

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[4] Part of the British problem has been with the *distribution* of its talented professionals. Although Britain has had a great basic science capability, her science and engineering capabilities *in private industry* have been much less impressive.

It seems obvious from the Japanese experience that, given the appropriate engineering, managerial, and organizational skills, a high degree of economic competitiveness can be attained by drawing upon more advanced technologies that are available abroad and that are the product of scientific research conducted abroad. It is, to put it the other way around, easy to exaggerate the purely economic significance of a first-rate *domestic* scientific research capability when it does not exist together with the complementary "downstream" skills discussed earlier. To be more precise, such scientific capabilities are certainly not a *sufficient* condition for economic competitiveness and growth. They are almost certainly becoming a more frequent *necessary* condition, if only because earlier access to new research findings can be translated into a lead-time over one's competitors that may be highly advantageous. However, I have to admit how impressed I am with the number of instances where, in the recent past, it has not even been a necessary condition for the Japanese.

All this should not be totally surprising. The fruits of purely scientific research have always been highly portable. What I am now suggesting is that events of recent decades are rendering the findings of technological innovation highly portable internationally as well-at least under the right set of circumstances in the recipient countries. By the right set of circumstances I mean the cluster of capabilities associated with the ability to commercialize new products or processes, i.e., the skills that lie further "downstream" from purely scientific research capabilities. At the macroeconomic level, I mean a stable economic environment that is conducive to investment activity and especially to the willingness of people in industry to make decisions on the basis of long time horizons. This brings me to my final set of comments.

III

In considering America's growing difficulties in translating the findings of basic research into commercially-successful new products, it has to be emphasized that the relevant criteria are not scientific ones. Nor are they even technological. The relevant criteria are ultimately and inescapably economic. Technological success is, of course, a necessary condition, but it is not sufficient. In fact, the main uncertainties in the innovation process are not over whether a new product design will "work" - whether a new airplane will fly or a new power generator will produce a flow of electricity, or even whether they can be made to perform according to their original design specifications. The ultimate criterion is whether the product can be sold at prices, and in quantities, that will justify all the expenditures incurred in bringing it to market. AT&T offered the public a "picture-phone" 25 years ago, which certainly transmitted pictures as well as sound, but the public could not be induced to subscribe at anything like the rates at which the service was marketed. The Concorde is a brilliant engineering accomplishment that can span the Atlantic in about 3 hours, but only 16 were produced before manufacture was discontinued. Moreover, all the original sales were to the nationalized airlines of France and Great Britain - entities that were hardly in a position to evaluate the product in purely economic terms. The airplane has been, simultaneously, a technological success and a commercial disaster.

Thus, success in the introduction of new products is ultimately determined by economic considerations. New products derived from research must first be incorporated into forms that perform well and that cater to a consumer need for which markets exist or can be created. Moreover, in an economic context where, as we have seen, new technologies rapidly become available to overseas producers, the critical issue is no longer the ability to *devise* the new products but to win out in intensely competitive international markets for these products. The ability to do so involves a number of additional considerations that significantly shape a country's economic performance. I would like to call attention to one set of considerations that I believe are of decisive importance in determining American competitiveness in the markets for new high technology products.

It has become fashionable in recent years to deplore American industry's excessive preoccupation with short-term measures of economic performance. American management and business decision-makers generally have been criticized, not only for their narrow "bottom line" mentality, but for their excessive concern with a bottom line that is not farther down the road than the next quarterly report.

It is no part of my intention to offer an apologia for myopic business decision-making. On the contrary. What I would like to suggest - and you don't need to be an economic determinist or even an economist to suggest it - is that there are some compelling forces in the American macroeconomic environment that have been strongly conducive to such myopia. Criticisms that fail to recognize such forces while deploring the short time horizons, are, at best, superficial. Moreover, I would like to suggest that the fundamental reason for short time horizons is also intimately linked to the reasons for the unacceptably slow growth in U.S. productivity in the last 15 years or so.

According to the U.S. Department of Labor, the growth in real product per employee hour between 1948 and 1973 was almost 3% - 2.9%. It declined sharply after 1973, and averaged 0.6% for the period 1973-81. It has recovered from the poor performance of the 1970s, and grew at 1.4% for the recent period 1981-85. But this is still far below the level that prevailed from 1948-73 (less than half).

The underlying macroeconomic facts that connect business myopia and slower productivity growth can be simply stated: In a variety of ways and for a variety of reasons, the American economy in recent years has been generating low rates of net savings and capital formation, rates that are far lower than those of our main overseas competitors. The American economy has indeed operated with short time horizons, which is to say that it has heavily discounted the future in favor of the present. But this is the inevitable consequence of being a society that devotes only a very slender amount of resources to saving - i.e., to withholding the use of resources from present consumption and making them available for purposes that increase *future* productivity - i.e., investment. To say that an economy has a low level of net saving is the same as saying that it attaches a low priority to using resources in ways that will raise productivity in the future. Such preferences are reflected in high rates of interest - i.e., a high rate of discounting of distant benefits. Such high rates of discount, in turn, *dictate* a short time horizon in business decision-making. Investments in either physical plant or in R&D that yield substantial benefits, but only in the more distant future, simply fail to meet the most elementary market tests in an economy with low savings and high rates of interest.

There can be no doubt that the description I have just offered constitutes a close fit to the American economy in recent years, and underlies both business myopia and slow productivity growth. Rates of net saving in America have declined sharply. From an annual average of almost 7% of GNP (6.9%) in the 1950s, and about 7.5% for the 1960s, net savings declined to barely 6% (6.1%) in the 1970s and then declined much more sharply in the 1980s. Between 1982 and 1986, net savings averaged 2.3% of GNP, and in 1986 it was a mere 1.9% (see Table I). That is, most emphatically, no way to run an expanding industrial economy in a highly competitive world! (The Japanese net saving rate in the 1980s has been running at over 17%.) A high rate of saving translates into a low cost of capital. A low cost of capital, in turn, translates into long time horizons. Conversely, low rates of saving translate into a high cost of capital - and business myopia.

In order to appreciate the full economic significance of the low level of saving and investment for low productivity growth in the U.S.

and for the economy's deteriorating competitive position, it is vital to make connections with another postwar trend of massive importance. I refer to the rapid rate of growth in the size of the American labor force. The ability of the American economy to generate new and enlarged employment opportunities, in order to accommodate the postwar baby boom and the rising labor force participation of women, is one of the most remarkable, if unsung, economic achievements of the postwar period. In the decade of the 1970s alone, the employed labor force grew by no less than 20 million (from 80 million in 1970 to 100 million in 1980). For the 30 year period from 1955 to 1985 the American economy created 45 million new jobs. To provide some basis for comparison, the European Common Market countries created 5 million new jobs during that same period.

That is the good news. The bad news is essentially the other side of the coin of the good news. (You might say that the bad news is that we couldn't *afford* the good news.) That is, the absorption of this flood of new entrants into the labor force, many of them with little or no previous job experience or training, meant a drastic slowdown in the rate of growth of labor productivity. The slow growth in U.S. labor productivity is, in a fundamental way, a consequence of the rapid expansion in the employed labor force. However, it is only by directly juxtaposing two separate trends - low rates of saving and investment and a high rate of new entry into the labor force - that the full magnitude of America's growing problems in international competitiveness, and slow productivity improvement, becomes apparent.

A major determinant of labor productivity is the capital/labor ratio. In very considerable measure, improving labor productivity is a matter of equipping each worker with an expanding stock of machinery and equipment. And of course, when the labor force itself is growing very rapidly, high rates of capital formation become even more important in providing a basis for continued productivity improvement. There is a high correlation, internationally, between a country's growth in labor productivity and the growth in its capital/labor ratio. In these respects the comparative strength of the American economy has deteriorated rapidly over the past 20 years or so. Whereas the capital/labor ratio grew by 3% per year between 1948 and 1973, after 1973 it slowed to an annual growth rate of less than 2% per year. In sharp contrast, the annual amount of fixed investment per manufacturing worker in Japan is more than twice as high as in America, and the difference is growing wider.

In the context of rapid technological change and, more especially, the rapid international diffusion of technology, the implications of these trends become even more serious. The cost of capital shapes the willingness to invest resources in the development of new technological possibilities opened up by scientific research. It subsequently determines the speed with which such new technologies will be embodied in new forms of machinery and equipment, and the speed and the extent to which firms will ultimately adopt and exploit these new technologies. And it also determines the ability to supply a rapidly-expanding labor force with the equipment needed to raise productivity and maintain competitiveness.

Of course, this is not the whole story. The American economy has been subjected to an exceptionally high degree of volatility in the 1970s and 1980s. Outside events, such as the Arab oil embargo and the subsequent runup in energy prices, were highly disruptive and led to great uncertainty, fear of future inflation, and erratic changes in government monetary and fiscal policies that led to an even greater reluctance to make long-term commitments. The preoccupation with short-term problems has contributed to an economic environment that has been increasingly inhospitable to the stability required for carrying out long-term R&D strategies.

One conclusion is, I believe, therefore unavoidable. The impact of science, and of R&D activities generally, is not something that can be meaningfully discussed outside of an economic context. Insofar as the concern with scientific research and, more broadly, R&D, are generated by their possible contribution to economic competitiveness and growth, it needs to be recognized that those contributions are directly shaped and mediated by conventional economic variables. Indeed, I would be inclined to conclude by saying that there really is no such thing as a meaningful science policy independent of economic policy.

TABLE I

U.S. NET SAVING AND INVESTMENT, 1951-86

	1951-60	1961-70	1971-80	1981	1982	1983	1984	1985	1986
Total Net Saving	6.9%	7.5%	6.1%	5.2%	1.6%	1.8%	4.0%	3.1%	1.9%
Net Private Saving	7.2	8.0	7.1	6.1	5.4	5.9	7.4	6.5	5.4
Personal Saving	4.7	4.7	4.9	4.6	4.4	3.6	4.3	3.2	2.8
Corporate Saving	2.5	3.3	2.2	1.4	1.0	2.3	3.2	3.3	2.6 —
State-Local Govt. Surplus	-0.2	0.1	0.9	1.3	1.1	1.3	1.4	1.5	1.4
Federal Govt. Surplus	-0.2	-0.5	-1.9	-2.2	-4.8	-5.4	-4.8	-4.9	-4.9
Total Net Investment	7.0%	7.5%	6.3%	5.4%	1.6%	1.8%	3.8%	3.0%	2.7%
Net Foreign Investment	0.3	0.5	0.1	0.2	-0.2	-1.0	-2.6	-2.8	-3.4
Private Domestic Investment	6.7	7.0	6.2	5.2	1.8	2.9	6.4	5.8	5.5
Plant and Equipment	2.7	3.5	3.0	3.1	2.0	1.5	2.4	2.9	
Residential Construction	3.2	2.5	2.5	1.3	0.6	1.8	2.4	2.4	5.2
Inventory Accumulation	0.8	1.1	0.7	0.9	-0.9	-0.4	1.6	0.2	0.3
Memoranda: Capital Consumption	8.9%	8.5%	9.9%	11.2%	11.7%	11.4%	11.0%	11.0%	10.8%
Gross Private Saving	16.1	16.4	17.0	17.2	17.1	17.3	18.4	17.5	16.2

Notes: Data are averages (except for 1981-84) of annual flows, as percentages of gross national product.
Total net saving and total net investment differ by statistical discrepancy.
Detail may not add to totals because of rounding. 1986 figures are preliminary.
Source: U.S. Department of Commerce.

Senator **Sarbanes**. We are indebted to both of you for, I think, very effective testimony.

I want to ask the following. Both of you focused, obviously, on Japan, and there is a great tendency now whenever we are discussing our competitiveness problem in whatever area, to look at the Japanese, for obvious reasons.

To what extent should we be looking at what West Germany, France, and some of the other countries are doing? Are there lessons that we can draw from their experience that may be more immediately relevant than what we may draw from the Japanese, given the difference in cultures that are involved between ourselves and the Japanese?

Mr. **Rosenberg**. I focused on Japan partly in the interest of economizing on time and partly because in many respects recently the Japanese have been the most effective of our foreign competitors. I think some of the things we can learn from Japan we can learn quite independently of the cultural differences, which admittedly are very great.

From the point of view of the kinds of macroeconomic factors that I have been emphasizing, it seems to me we can really put together Japan and Western Europe, particularly West Germany, with respect to the importance of policies that are favorable to savings and capital formation. If you array the countries of Western Europe and Japan—say, the OECD countries for short—you find a very close correlation between the rates of capital formation in the country and their rates of productivity growth.

The correlations become even sharper when you focus it down to improvements in the capital-labor ratio and relate that to the rate of productivity growth per country. I think there are some lessons that we can indeed learn from both the Japanese and the Western Europeans. Putting that lesson negatively, it is that the costs of becoming a low-savings and a low-capital-forming economy are likely to be very high in terms of our declining productivity growth and future competitiveness.

Mr. **Mansfield**. I agree largely with what has just been said. In the interest of time, I won't say too much on this score. But first, I think that France is not as close, perhaps, to the United States as might be thought, because the French have a long tradition of considerable government intervention in the economy, which is quite different from here.

Also, they have a substantial nationalized sector, and so a lot of the policies that have been adopted there wouldn't be ones that would be readily considered here. I think it is fair to say that most people who have studied the French experience have come away with the impression that they probably have not had policies there is this area that have been notable successes, although I am sure there are things that we might emulate and learn from the French.

Now, in Germany, I think that one of the points that immediately comes to mind is that they have a tremendously powerful chemical industry there. If you look in each one of these countries, you really don't look at a country, you look at a conglomeration of industries as well as a country and the Government.

The chemical industry in Germany is tremendously powerful, and the interaction between the Government and the chemical industry might be something that people here might take a look at.

One feature of Germany's technology policy is a credit they have for small- and medium-size firms to partially subsidize research and development there. Now, whether this is something that the United States would want to emulate is, I would think, questionable.

I agree with Nate Rosenberg that although the Japanese are different in many cultural elements, that a lot of what they have done and a lot of the data pertaining to them certainly have implications for our performance and policies here.

Senator **Sarbanes**. Mr. Rosenberg, in your table, what is the line "Capital Consumption"? Could you elaborate on that a little bit? It is almost at the bottom.

Mr. **Rosenberg**. Yes. The capital consumption is basically the allowance for the depreciation of capital. These figures here are intended to focus on net savings and net investments. So, they are net after allowance for the replacement of wornout capital equipment, basically.

Senator **Sarbanes**. And therefore, what is the significance of the larger figures in the 1981–86 period?

Mr. **Rosenberg**. Which larger figures?

Senator **Sarbanes**. For capital consumption. The percentage figures have gone up from around 9 to 10 percent to over 11 percent.

Mr. **Rosenberg**. Yes. Well, those figures were the increase as a result of an expanding capital stock and an increasingly aging capital stock. These things would necessitate that in any year a larger amount of resources had to be devoted to the replacement process.

Senator **Sarbanes**. What is behind those figures? Does that show that we simply have an aging capital stock and, therefore, a larger percentage goes into capital consumption each year? Or does it reflect some other factor?

Mr. **Rosenberg**. It would have at one point. It is also affected, of course, by changes in tax legislation, the question of what is allowable for tax purposes. You will note that although it has increased in the early 1980's it has also begun to decline again toward the very end, in the last 3 years or so.

I am anxious to emphasize in that table the very small proportion of our gross national product which is being devoted to making net additions to that stock of capital.

Senator **Sarbanes**. This is your total net investment figures, which has gone down from between 6 and 7 percent down to 2 to 3 percent, I guess one would say.

Mr. **Rosenberg**. That's right. That's right. The total net investment. And it is then further broker down into the domestic and foreign components.

Senator **Sarbanes**. And I guess the net foreign investment is the larger factor in that decline; is that correct?

Mr. **Rosenberg**. What is clear is that in recent years a much larger fraction of American net investment has been made possible by foreign investment in the United States, which is essentially the other side of the coin of the decline in net savings that has taken place during this period, net domestic savings.

Senator **Sarbanes**. I am not sure I have grasped the full implication of those figures. I want to make sure I understand it. Private domestic investment has dropped a bit, if you exclude the recession years of 1982–83, which I take it is why the figures are down as low as they were in those years; is that correct? That is a cyclical phenomenon here, essentially?

Mr. **Rosenberg**. Yes.

Senator **Sarbanes**. But private domestic investment has dropped somewhat although not anywhere near as much as the net foreign investment figure, to explain the decline in total net investment?

Mr. **Rosenberg**. That's right. That's right. Private domestic investment has declined within the United States from the earlier periods, as I have shown, for the 1950's 1960's, and 1970's. What has happpended in recent years is that given that amount of domestic investment that has taken place, a substantial fraction of it has been in effect financed by foreign investment in the United States.

We are, in effect, highly dependent at this point for our net investment activity upon the willingness of foreigners to continue to make investments in the American economy. And again, the other side of the coin of the decline in net domestic savings is the first row.

Senator **Sarbanes**. Congressman Scheuer.

Representative **Scheuer**. Thank you, Mr. Chairman.

The testimony has been really terrific. But I must be on the House floor at noon, so I only have a minute or two.

Let me just ask each of you one question. In terms of how Congress functions, in terms of promoting investment and a broad approach, the mission-oriented approach of a country like Japan has, that really focuses attention and support on one particular industry, and in our country where we have the breeder reactor, the space program, supersonic transport, and then other countries have a diffusion-oriented approach where they don't focus on a particular industry but they have general programs of assistance to education, to technical school-industry collaboration, and that kind of approach, and that would be typical of Germany, Sweden, and Switzerland.

Which of these two approaches do you think considering our unique mix of industry, universities, and so forth, makes the most sense for our country?

Should we specifically try to help industries, and in some cases even firms, with a national economic policy of a kind, or should we concentrate on creating a base, a wellspring of well-trained young people in science, math, engineering, support the university-industry collaboration, and then assume that the market forces will do the rest if we have well-trained people out there and good cooperation between industry and the universities?

Mr. **Mansfield**. May I ask a question? You are confining this question to civilian technology, I assume.

Representative **Scheuer**. Yes.

Mr. **Mansfield**. Although it is obvious that there has to be a mix, you are going to have particular industries, and areas where for a variety of reasons, partly noneconomic, you are going to want the Federal Government and Congress to support them. This has been the history of the United States. While in general we have espoused a philosophy that didn't always accentuate this, nonetheless it has been true.

At the same time, while there are such examples, my guess is that the second approach you describe tends to be the better general philosophy for the Government. If you look at those countries—France, as I mentioned before, is a very good illustration, and Britain is another—where they have tried to take over in considerable part the entrepreneurial role in technology, the results typically have not been very successful, whereas those countries that have tried to establish a proper climate have tended to do better. Moreover, this climate, I think entails some things that may not have been mentioned in your question, although I agree that part of it is education and basic science.

Representative **Scheuer**. Tax treatment?

Mr. **Mansfield**. Yes. And I would also include policies dealing with competition. Although I know that they are not in quite such favor today, I think that certain elements of antitrust policy and policy which aims at keen competition among the firms in the economy are very important.

Mr. **Rosenberg**. I am certainly in broad agreement with Professor Mansfield's statement. I think the experience that we have had in the post war years in having Government agencies attempt to pick technological winners have not been a very favorable experience either in the United States or Western Europe generally. I think the British experience is a particularly strong one there.

I would like to emphasize, though, that I think that we may be exaggerating the role that MITI has played in Japan as an actual selector of specific technologies. In fact, the Japanese Ministry of Finance played rather a more important role in the earlier post war years.

In general, I think it would be truer to say that what the Japanese have done in the post-World War II years has been, especially more recently, to provide a macroeconomic environment that is stable, that is conducive to making investment decisions on a long-term basis, an environment that is generally favorable to savings and capital formation itself, particularly the savings and that the Japanese success story I think is much more one of providing those overall environmental type incentives for the economy.

This become particularly clear, by the way, if you look at the financing of their R&D expenditures. In spite of all of the talk about MITI and its galvanizing and controlling role, the fact is that a substantially higher fraction of all R&D in Japan is financed privately.

Now, in considerable measure, this is due to the large role that defense plays in the American budget. But even if you take out the defense component, it still remains true that if you take the nondefense R&D that that chart refers to over there [indicating], a larger fraction of that is privately financed in Japan than is the case in the United States.

Representative **Scheuer**. Thank you very much.

Thank you, Mr. Chairman.

Senator **Sarbanes**. Gentlemen, we thank both of you. It has been a very helpful panel.

The committee stands recessed.

[Whereupon, at 12:01 p.m., the committee recessed, to reconvene at 9:30 a.m., Friday, December 11, 1987.]

INVESTMENT IN RESEARCH AND DEVELOPMENT

FRIDAY, DECEMBER 11, 1987

CONGRESS OF THE UNITED STATES,
JOINT ECONOMIC COMMITTEE,
Washington, DC.

The committee met, pursuant to recess, at 9:45 a.m., in room SD-628, Dirksen Senate Office Building, Hon. Paul S. Sarbanes (chairman of the committee) presiding.

Present: Senator Sarbanes and Representative Scheuer.

Also present: William Buechner, professional staff member.

OPENING STATEMENT OF SENATOR SARBANES, CHAIRMAN

Senator SARBANES. The committee will come to order.

Mr. Ambler, if you would come forward here, we would appreciate it.

This morning the Joint Economic Committee holds its second hearing on the Federal role in the Nation's research and development programs. These hearings are part of the committee's focus on what we have termed "prudent investment issues," as the committee seeks to identify those areas of the economy in which prudent investment is critical to the Nation's future economic strength.

Today, as in the first hearing on this subject held a little over a week ago, the committee will attempt to assess the strengths and weaknesses of Federal research and development programs, and the role of the Federal Government in facilitating research and development in the private sector.

The committee's inquiry is prompted by concerns outlined earlier this year in the 1987 annual report of the Joint Economic Committee.

The first is the dramatic shift in the focus of the Federal investment in R&D programs, from roughly a 50-50 split between defense and nondefense programs from the mid-1960's to 1981, to a split of 70-30 defense-nondefense today.

The second is the failure of the U.S. investment in nondefense research and development, measured as a percent of GNP, to keep pace with comparable investments by West Germany and Japan. And that's very sharply illustrated in this chart—nondefense R&D as a percentage of GNP comparing Japan and West Germany with the United States.

The Joint Economic Committee will focus attention today on two critical aspects of research and development in the United States:

First, the process by which U.S. businesses create commercial applications from basic scientific knowledge; and second, the current situation in graduate education in science and engineering.

The committee will first hear from Mr. Ernest Ambler, Director of the National Bureau of Standards. Following Mr. Ambler, we will have a panel consisting of Mr. Joseph Saloom, senior vice president of M/A COM, Inc., and chairman on the Council on Research and Technology; Mr. Kenneth Flamm, senior fellow at the Brookings Institution, representing the Council on Competitiveness; and Mr. Daniel Burton; vice president of the Council on Competitiveness. Then we will close with a panel consisting of Miss Betty Vetter, executive director of the Commission on Professionals in Science and Technology; and Mr. Alan Fechter, executive director of the Office of Scientific and Engineering Personnel at the National Research Council.

Mr. Ambler, we are very pleased to have you before us this morning and we look forward to hearing your testimony.

Congressman Scheuer, did you have a statement?

Representative SCHEUER. I don't have a statement, Mr. Chairman.

Senator SARBANES. At the request of Senator D'Amato, his opening statement will be placed in the record, without objection, at this point.

[The written opening statement of Senator D'Amato follows:]

WRITTEN OPENING STATEMENT OF SENATOR D'AMATO

MR. CHAIRMAN, I WOULD LIKE TO WELCOME TO THE JOINT ECONOMIC COMMITTEE THIS MORNING OUR DISTINGUISHED PANEL OF WITNESSES WHO WILL CONTINUE THE DISCUSSION ON THE ROLE OF GOVERNMENT INVESTMENT INTO RESEARCH AND DEVELOPMENT.

THE UNDENIABLE MERITS OF RESEARCH AND DEVELOPMENT WERE DISCUSSED AT LAST WEEK'S HEARING. WE ALL SEEM TO AGREE UPON THE NECESSITY TO CONTINUE TO SEEK METHODS IN WHICH R&D MAY BE STIMULATED AND ENCOURAGED. REASONABLE TAX CREDITS REMAIN ONE OF THE MOST VIABLE DEVICES IN PROVIDING INCENTIVES TO COMPANIES ENGAGED IN RESEARCH AND DEVELOPMENT ACTIVITIES.

IT IS IMPORTANT TO KEEP THE UNITED STATES AT THE FOREFRONT OF TECHNOLOGY. AS THE WORLD'S INDUSTRIAL GIANT, WE MUST NOT ALLOW OURSELVES TO BE SURPASSED BY THE OTHER INDUSTRIAL STRENGTHS IN THE WORLD.

I LOOK FORWARD TO THE TESTIMONY OF OUR WITNESSES THIS MORNING AND TO THE INSIGHT THEY ARE SURE TO PROVIDE THIS COMMITTEE ON THE IMPORTANCE OF INVESTING IN RESEARCH AND DEVELOPMENT.

THANK YOU, MR. CHAIRMAN.

Senator **Sarbanes**. Mr. Ambler, if you would proceed, we would be happy to hear from you.

STATEMENT OF ERNEST AMBLER, DIRECTOR, NATIONAL BUREAU OF STANDARDS, DEPARTMENT OF COMMERCE

Mr. **Ambler**. Thank you, Mr. Chairman and Congressman Scheuer.

I am very pleased that you asked me to take part today in your review of the current state of research and development in the United States and to examine options for improving the Federal Government's policies and programs in these areas.

The Government supports research and development for a variety of reasons, such as our defense, for health care, a better environment, and so on. Since roughly around the end of the Second World War, the Federal Government has assumed, principally, I think, through the National Science Foundation, a major role in supporting scientific research in our universities for the purpose of training students and for the general pursuit of new knowledge.

Today in our country I believe our greatest concern is in applying the results of R&D to benefit our economy. The trade deficit, our lack of competitiveness in global markets, and our need to improve productivity and quality are of great concern to all of us. It is natural for us to ask how the billions of dollars' worth of research and development supported by the Government can help in improving our economy.

The President has set the framework for facilitating the use of the results of this Federal research and development. His April 10, 1987, Executive Order No. 12591, based on the Federal Technology Transfer Act of 1986 and the University and Small Business Patent Procedures Act of 1980 leads the way. He has directed all Federal agencies to encourage and facilitate collaboration among Federal laboratories, State and local governments, universities, and the private sector, particularly small business, in order to assist in the transfer of technology to the marketplace.

This morning I'd like to focus on the role of the Federal laboratories in helping to transfer technology to the private sector. And, my opinions, Mr. Chairman, are based on the experience of the National Bureau of Standards which has as its primary mission stated clearly in its enabling legislation the function of serving U.S. industry in very specific ways.

At a time when so much attention is being placed on the possibilities of technology transfer, I believe we should face the fact that technology transfer is no easy task and that it can never be taken for granted.

Another fact, in my opinion, is even more telling. While many of the Federal laboratories can and should play an important role in supporting industry, the Government has never been successful in showing industry how to do its job. There is absolutely no reason to think that this will change in the future. Developing products and getting them ready for market is a private sector job and not the Federal Government's. It's my belief that the responsibility lies primarily in that direction.

So the question in my way of thinking is not what is the magic formula for transferring technology to industry. The question is, I would submit, what kind of support can Federal laboratories give U.S. industry? And I assume, of course, that U.S. industry knows where its going and what it needs and what kind of help it can use from others and is willing to use from others.

Our own experience at the National Bureau of Standards has proven that the best formula for successful technology support mixes the pool of talented researchers and the specialized facilities in Federal laboratories together with the staff of forward-thinking companies. Most importantly, it is absolutely vital to get the active involvement of industry right from the start. That is to say, in the program planning and the conceptualization of what you're going to do.

At the National Bureau of Standards, we have always worked cooperatively with the private sector. In fact, we have done so much work with and for industry, I know, for example, that I could quote examples of how NBS has worked and transferred technology to companies in the jurisdictions of every member of this committee.

We do it in a variety of ways. For example, nearly 200 scientists and engineers from companies or trade associations are working in a formal way at NBS under our research associate program. Through this program, sponsoring firms or organizations pay their employees' salaries while they work with our staff in NBS laboratories on problems of mutual interest. This ensures our work is relevant and immediately helps those companies, and eventually other companies benefit as well since the results are published in the open literature. The companies which join this program get a bonus since now they can retain exclusive rights to patents based upon the cooperative research.

This program allows us to conduct some research that we otherwise could not do. Technology transfer is built in from the beginning with the definition of the work to be done and by establishing personal continuing connections.

We also host top scientists and engineers from industry and universities for various durations in a less formal way through a program for guest researchers. About 700 such experts come to our laboratories each year with a blend of academic, government, and industrial research interests.

Another way in which we collaborate with industry, one that may be unique in the Federal Government, is a cost-sharing mechanism. Many companies loan or donate to NBS equipment or materials for experimentation. Last year, we had nearly 12 million dollars' worth of equipment and materials either loaned or given to us by dozens of companies. It is not just the big companies that are chipping in, either. Contributions range from 500 dollars' worth of precision ball bearings to $3.5 million of computer equipment.

In addition to arrangements with individual companies, we have also formed research consortia and other cooperative arrangements in just about every way possible. These involve groups of companies, and sometimes agencies, which often pay a share to have NBS conduct research for the group. In other cases, NBS plays a lead role in organizing and helping keep together groups of interested firms and agencies in cooperative work where no funds may be exchanged between the various cooperating parties.

Our facilities are a key drawing card for attracting companies to NBS in a way that encourages technology transfer. We have had a longstanding policy permitting NBS facilities to be used for collaborative research. For instance, more than 300 specialists from industry, universities, and other agencies use our nuclear research reactor each year. Recognizing the growing need to help put the best facilities at industry's disposal, in light of the competitive situation, more recently we have made several of our facilities available for proprietary use.

We also use workshops, conferences, and participation in standards committees as ways to work with individual scientists and engineers in identifying and solving problems. We held more than 100 major conferences and 600 workshops and seminars last year, bringing together thousands of experts from around the world. Our employees have more than 1,400 memberships on standards committees and in most of those meetings NBS researchers sit alongside industry experts, contributing their technical expertise and listening to what industry says it needs from NBS.

To illustrate how these various technology transfer mechanisms work, in my prepared statement, Mr. Chairman, I have some examples of those activities. For example, in automation, in semiconductors, biotechnology, medical measurements, and so on. And we have scores of other examples of successful technology transfer through cooperative work.

Senator SARBANES. The entire prepared statement will be included in the record. So if you want to summarize the examples, that's fine.

Mr. AMBLER. Well, thank you, Mr. Chairman. If it's all right with you, I won't go into them any further because they are in the record.

Senator SARBANES. Fine. Very good.

Mr. AMBLER. At the last count, we had about 250 active formal collaborative projects. We constantly are in search for new partners for research that will help both NBS and the private sector to accomplish their goals. And we have published, Mr. Chairman, this special brochure that describes many of the opportunities for cooperative research at NBS. It's called "Cooperative Research Opportunities at NBS," and I would like to submit this for the record, Mr. Chairman, if you find that acceptable.

Senator SARBANES. It will certainly be included.

Mr. AMBLER. I would also like to submit this brochure that describes the facilities of the National Bureau of Standards which gives an idea of what's available at the National Bureau of Standards, which I imagine is typical of many of the national laboratories that would be available I'm sure for use by the private sector.

Senator SARBANES. If you could submit 20 of each, we would make sure that each member of the committee received a copy. While I know many members are familiar with the work of the National Bureau of Standards, I think perhaps not all, and this would be a way of updating them. Would that be possible?

Mr. AMBLER. Yes, sir. We will submit 20 copies.

Senator SARBANES. Fine. Thank you very much.

Mr. **Ambler**. As I look back on what I've just said about our cooperative work with industry, my thoughts go back to 1982 when I wrote an editorial for Science magazine, hoping to get some sort of tips based on our own experience about cooperating with industry. At the time, I'm sorry to say, that attracted absolutely no attention and I guess that was that. But I was reading the article recently and it seemed to me just as relevant today, and with your permission, I'd like to give it another try and suggest that you might wish to include this in the record. It's very short, Mr. Chairman, just one page.

Senator **Sarbanes**. We would be happy to do so.

Mr. **Ambler**. I would like to summarize some of the lessons that are outlined in this article based on our own experience just very quickly to give you an idea of what we think it takes to make cooperative research work.

The first thing is, you have to know industry's needs and focus resources to match those needs. In a way, it's absolutely no different from what industry calls market research. You have to do that.

You have to make sure you have the facilities and the expertise and the people and the dedication to do the job well. You either are willing to do that or your shouldn't try at all. You have to do the job on time. Industry will not tolerate empty promises or untidy results, and quite rightly so. And as we all know, it doesn't take the private sector very long to jump on the Government. So it's a very good idea not to give them any excuse for not showing that you're a real heads-up organization, which many Federal agencies are.

I don't think one should assume that the task has to be very large. Often one wants to think of a very big deal. Often it's the smaller projects with a very limited but well defined objective that are most useful to industry. And it needn't be a long term. You can get a tremendous amount of useful stuff done just by collaborations of a few weeks or a few months and just between a few people.

Then the other thing is to constantly monitor the direction of the collaborative program and change it when it's necessary. That is, set up efforts that are spinoffs, scale up the project, scale it down. Sometimes they don't work out so don't be afraid to stop them. And always be on the lookout for new opportunities.

I think most scientists and engineers in the course of conducting their own profession know what's going on out in universities and other government agencies and the private sector, and they should use that to educate themselves as to what they feel the needs of the private sector are in relation to their organization, and be attentive to detail and flexible and be persistent.

One of the things that one finds in working with the private sector is that they are very demanding on your time. They really like to know constantly what's going on and that's very good because it means the technology transfer is going very quickly. But it does take a great deal of time.

Congress seems to have recognized the success NBS has had in technology transfer. Consequently, the House and Senate are considering expanding the role of NBS and renaming it the National Institute of Standards and Technology to take into account this proposed broader mission.

Among other things, the legislation calls for us to build upon the very successful automated manufacturing research we have been conducting by helping to set up regional manufacturing technology centers. These centers would speed the transfer of this technology to the many firms around the country that need to put new automated manufacturing techniques into practice in order to meet the challenge of foreign competitors.

I would look forward to working more closely with regional technology centers. In fact, I believe that this is the direction in which we should try to move whether the present legislation becomes law or not—to work with State and local governments in regional activities.

So that's the way we see the whole subject from the Bureau of Standards, Mr. Chairman, and I really appreciate having had the opportunity to explain the way we see things and I would be glad to answer questions if you have them.

[The prepared statement of Mr. Ambler, together with the material referred to for the hearing record plus additional material, follows:]

PREPARED STATEMENT OF ERNEST AMBLER

Mr. Chairman and members of the Committee:

I am pleased to be here today to take part in your review of the current state of research and development in the United States and to examine options for improving the Federal Government's policies and program in these areas.

The Government supports research and development for a variety of reasons such as our defense, health care, a better environment and so on. Since the 2nd World War the Federal Government has assumed, principally through NSF, a major role in supporting scientific research in our universities for the purpose of training students and for the general pursuit of new knowledge.

Today I believe our greatest concern is in applying the results of R&D to benefit our economy. The trade deficit, our lack of competitiveness in global markets, and our need to improve productivity and quality are of great concern to all of us. It is natural for us to ask how the billions of dollars worth of research and development supported by the Government can help in improving our economy.

The President has set the framework for facilitating the use of the results of this Federal research and development. His April 10, 1987, Executive Order 12591 based on the Federal Technology Transfer Act of 1986 (P.L. 99-502) and the University and Small Business Patent Procedures Act of 1980 (P.L. 96-516) leads the way. The President wants to ensure that Federal agencies and laboratories assist universities and the private sector in broadening our technology base by moving "new knowledge from the research laboratory into the development of new products and processes." He has directed all Federal agencies to encourage and facilitate collaboration among Federal laboratories, State and local governments, universities, and the private sector, particularly small business, in order to assist in the transfer of technology to the marketplace.

While many of the Federal laboratories can and should play an important role in supporting industry, the government has never been successful in showing industry how to do its job, and there is absolutely no reason to think that this will change in the future. Developing products and getting them ready for market is the private sector's job, not the Federal Government's.

So the question is not "What is the magic formula for transferring technology to industry?" The question is, "What kind of support can Federal laboratories give U.S. industry?" (I assume, of course, that U.S. industry knows where it is going, what it needs and what help it can use from others.)

As you know, NBS has a unique legislated mission, among Federal labs; it is specifically directed to support U.S. industry. While this is not the mission of most Federal labs, I feel that many of the lessons learned at NBS are transferable to other Federal labs.

Our own experience at NBS has proven that the best formula for successful technology support mixes the pool of talented researchers and the specialized facilities in Federal laboratories together with the staff of forward-thinking companies. Most importantly, it is absolutely vital to get the active involvement of industry right from the start.

At NBS, we have always worked cooperatively with the private sector. In fact, we have done so much work with and for industry, I guarantee that we can cite examples of how NBS has transferred technology and has helped companies and other organizations in the jurisdictions of each member of this panel.

We do this in a variety of ways. Nearly 200 scientists and engineers from companies or trade associations are working in a formal way at NBS under our Research Associate Program. Through this program, sponsoring firms or organizations pay their employees' salaries while they work with our staff in NBS laboratories on projects of mutual interest. This ensures our work is relevant and helps not just those companies, but other firms as well, since the results are published in the open literature. The companies which join this program get a bonus, since they can retain exclusive rights to patents based upon the cooperative research.

This program allows us to conduct some research that we otherwise could not do. Technology transfer is built in from the beginning with the definition of the work to be done and by establishing personal connections.

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Another way in which we collaborate with industry, one that may be unique in the Federal Government, is a cost-sharing mechanism. Many companies loan or donate to NBS equipment or materials for experimentation. Last year, we had nearly $12 million worth of equipment and materials either loaned or donated to us by dozens of companies. It is not just the big companies that are chipping in, either. Contributions range from $500 worth of precision ball bearings to $3.5 million of computer equipment.

In addition to arrangements with individual companies, we have also formed research consortia and other cooperative arrangements in just about every way possible. These involve groups of companies, and sometimes agencies, which often pay a share to have NBS conduct research for the group. In other cases, NBS plays a lead role in organizing -- and helping to keep together -- groups of interested firms and agencies in cooperative work where no funds are exchanged and each party contributes its own time and effort.

Our facilities are a key drawing card for attracting companies to NBS in a way that encourages technology transfer. We have had a long-standing policy permitting NBS facilities to be used for collaborative research. For instance, more than 300 specialists from industry, universities, and other government agencies use our nuclear research reactor each year. Recognizing the growing need to help put the best facilities at industry's disposal in light of our competitive situation, more recently we have made several of our facilities available for proprietary use.

We also use workshops, conferences, and participation in standards committees as a way to work with individual scientists and engineers in identifying and solving problems. We held more than 100 major conferences and 600 workshops and seminars last year, bringing together thousands of experts from around the world. Our employees had more than 1400 memberships on standards committees. In most of those meetings, NBS researchers sit alongside industry experts, contributing their technical expertise and listening to what industry says it needs from NBS.

To help illustrate how these various technology transfer mechanisms work, I would like to review a few examples.

NBS Automated Manufacturing Research Facility.

The NBS Automated Manufacturing Research Facility, or the AMRF, emerged out of our programs to help U.S. firms make precisely machined parts.

As far back as the 1960s, we had started planning to deal with the effect automation would have on our measurement services, particularly in the machining and gaging of parts. We saw new demands being placed on us by industry for measurement and interface standards. We saw the need developing to measure on-line and to use feedback to make more accurate parts. We also saw standardization barriers which could inhibit manufacturers from interconnecting different automated equipment, and thereby from taking full advantage of automation.

The problem seemed likely to be particularly severe for manufacturers who make parts in small numbers, that is, in batch manufacturing, as opposed to the big, mass production lines.

Together with industry, universities and government agencies --notably the U.S. Navy -- NBS researchers have come up with an automation research laboratory that is a proving ground for the technology of America's machine shops in the 21st century..

As the country's most advanced laboratory form of a flexible metal-working shop, the AMRF is a research version of an advanced, flexible manufacturing system made up of robots, machine tools, and computers.

A major focus of the AMRF has been on breaking down the barriers for linking these different components so that 100,000 machine shops around the country -- mostly small operations -- could take advantage of the latest automation technology.

All machines are U.S. made and they are all from different manufacturers. In other words, from the beginning, we set out to make the integration and compatibility job as difficult as possible in order to address the interface standards issue.

An equally important focus at the AMRF has been on quality. We saw the potential to use automation techniques to revolutionize the quality of manufactured products. Specifically, our researchers have shown that measurement can be built right into the manufacturing process, to make sure that parts can be made right the first time and every time. Such things as machine distortion and tool wear can be detected and corrected. You get a more precise part with less waste, you get it a lot faster, and you can cut set-up time down to nearly zero.

With industry's active involvement, NBS researchers have helped prove the concept of manufacturing by the use of computerized data -- starting with the design phase and continuing through manufacturing and inspection. This is true computer-integrated manufacturing.

Even though the full facility was not completed until last December and we are still incorporating new advances based on our latest research, industry already has picked up and commercialized AMRF results.

At least 10 voluntary industry standards have been adopted or under consideration due in part to support by the AMRF. At least 16 patents have been issued, and several have been licensed to industrial firms, as a result of work at the AMRF. We have tracked at least 20 commercial adaptations of AMRF research in new products and systems offered by U.S. firms.

We could not have done this work without industry's active cooperation and help. The project originally involved a Research Associate Program with just one firm who helped to identify key technical issues. A series of open houses and public demonstrations of our work led to increased private sector and Navy interest. We had more than 500 such visitors at our latest automation open house just last month.

Our interactions grew, and so did the scope of our research. More than 50 Research Associates from 3 dozen companies, both large and small, have participated in cooperative research projects at the AMRF since 1982. In addition, some of these sponsors have donated or loaned machine tools, robots, computers, software, and tooling. Their value exceeds $5.7 million. We have more than 50 connections with the academic research community.

Now that the experimental facility is in full swing, today we are placing a major focus on increasing technology transfer from the AMRF. For instance, to transfer AMRF principles and concepts into production, the South Carolina Research Authority, working under Navy sponsorship, has assembled a group of industrial firms into the American Manufacturing Research Consortium. It is building a development facility in Charleston, South Carolina, based on the AMRF. The result will be an automated production shop which then will be replicated during the early 1990s in Naval shipyards and rework facilities throughout the country.

Also, the Mare Island Naval Shipyard in California is working with NBS to develop a fully automated and instrumented manufacturing cell for production of parts used in Navy nuclear submarines.

Today, even as we continue to refine the concept and laboratory, we look for even better ways to move the lessons learned from this laboratory into the private sector, especially to smaller companies.

Integrated Circuit Linewidth Standards

During the 1970s, NBS produced Standard Reference Material 474. It is a microscope linewidth standard used to calibrate instruments, photomasks and systems used in making integrated circuits. The story behind the development of this SRM reflects the broader and deeper aspects of our measurement services and illustrates what it really takes to develop meaningful partnerships with industry. It also shows the importance and nature of "marketing" and technology transfer for a Federal laboratory.

The lines of material making up the different components in an integrated circuit are small and getting smaller. It is what is known in the trade as "the feature size". Industry is producing circuits with lines of about 1 micrometer and industry leaders are moving towards circuits with lines considerably smaller than that.

The width of integrated circuit lines is critical, but in the early 1970s, the semiconductor industry became aware that there was a problem, somewhere in the masking operations, with the control of critical dimensions. For example, suppliers of photomasks used to send their product to the integrated circuit manufacturers only to find nobody could agree on their measurements.

In 1973, a manufacturer of secondary linewidth standards asked us to provide a national standard for traceability, to help resolve the confusion.

We looked into the situation, and found that industry procedures, instruments -- and therefore measurements -- were seriously inconsistent. After a thorough analysis, we pinpointed the problem.

Remedying this problem was a major challenge for our research scientists, because it required the development of entirely new theories and measurement techniques. Over the next few years, our research produced information so fundamental and radically different from accepted theory and practice that it made basic changes in the direction of an entire industry. As a result of this work, the textbooks on the behavior of microscopes at very high resolution were literally rewritten, and new procedures were developed for measuring linewidth. These procedures were basic enough that they could be applied to all types of optical instrumentation from all manufacturers.

During this entire process, NBS scientists were in constant contact with all sectors of the user community, including manufacturers of instruments, photomasks, and integrated circuit devices. We reported regularly on our progress, built their interest, and made sure they agreed that we were on the right track. We worked closely with individual companies to help them decide how they could put our measurement results to use easily and swiftly on their existing systems.

We test marketed a Standard Reference Material to be sure it would work in practice, and, since the technique for using the SRM was very exacting, we ran week-long seminars and workshops to train industry specialists to use these new measurement tools to get better results.

The leverage of this reference material and our related services is tremendous. The program cost us less than $5 million over its lifetime of several years. But this year alone, due to widespread industry adoption of this method we estimate that savings of more than $30 million will be realized on a worldwide sales volume of $375 million in semiconductor device photomasks from merchant vendors alone. Despite the fact that this reference material was our most costly -- it sold for $5,016 dollars -- the demand has been overwhelming.

Medical Measurements

Clinical measurements are of growing importance not just for public health and safety, but for the economy as well. More than 7 billion clinical measurements worth close to $225 billion are made in the United States each year. U.S. manufacturers of the instruments used to make these measurements are the world leaders, and we still have a healthy balance of trade in this sector. By working with the instrument manufacturers and the medical community, NBS has helped to improve the quality of clinical measurements substantially. For instance, we have produced about 40 Standard Reference Materials to help make sure that equipment and test results are accurate.

Our cooperative activities are a cornerstone of this work. NBS collaboration with the College of American Pathologists (CAP) is a case in point. Since 1978, NBS and the 10,450-member organization of professional pathologists have worked together to overcome variances in test results among different clinical laboratories. Much of the time NBS and CAP have devoted to perfecting definitive analytical measurement techniques. Working side-by-side with NBS researchers, CAP-sponsored scientists have used these techniques to certify the accuracy of serum samples sent to laboratories. This was part of a CAP program to survey labs nationwide as a barometer of how well these labs are performing clinical tests.

We recently expanded our collaboration with CAP by establishing a reference laboratory program which initially aims to improve clinical measurements of blood serum cholesterol levels and drugs of abuse in urine.

Microwaves for Chemical Analysis

A joint project between NBS and CEM Corporation, a 100-person North Carolina manufacturer of research microwave equipment, offers a good example of how the NBS Research Associate Program can help small businesses through hands-on technology transfer. Working jointly in NBS laboratories, researchers from the Bureau and CEM designed a system that uses microwaves to dissolve chemical samples in closed vessels more safely and efficiently than traditional methods. The NBS-CEM team's work has led to a method for decomposing samples for analysis that takes less than 15 minutes. Older methods typically take anywhere from 4 hours to 4 days. The two key researchers, one from NBS and one from CEM, are editing a book for the American Chemical Society that will allow industrial chemists to predict conditions and to safely tailor their own microwave devices. They have given information and advice to more than 400 researchers from companies, universities, and research laboratories.

In September, CEM and NBS researchers were presented with an IR-100 award, an honor given annually by Research & Development magazine to recognize the 100 most significant new technical products of the year. It was one of 6 awards given to NBS in this year's competition.

"High-Temperature" Superconductivity

NBS has an unusually broad range of people and facilities for the study of nearly all aspects of the new high-temperature ceramic superconductors. We have a history of work in superconductivity dating back over 30 years, and have similarly been involved in ceramics research for decades. NBS has helped industry by developing standard measures for conventional superconducting materials, assisting with the applications of these materials in devices, and contributing to a better understanding of superconductors.

The NBS superconductivity program involves industry, university, and government agency researchers who look to NBS for special assistance and help us to get the job done. Companies such as IBM, AT&T, and Westinghouse, as well as the Naval Research Laboratory, universities, and other institutions regularly send samples of their high-temperature superconductors to the Bureau for careful characterization. Only from this type of detailed evaluation will scientists get a fix on the combination of compositional, structural, and electronic attributes that underlie high-temperature superconductivity.

Our recent collaboration with the Westinghouse Research and Development Center exemplifies the usefulness of working together with industry to help bring down the technical barriers standing in the way of commercial, high-temperature superconducting products.

High contact resistance has been one of those major obstacles. Resistance at electrical contacts causes heating in any device, but it is particularly fatal in superconductors. Even modest heating can raise the temperature of the superconductor enough to weaken or destroy the property of superconductivity. Working hand-in-hand, NBS and Westinghouse researchers produced a new method for making contacts which reduces electrical resistance by up to a million times compared with conventional contacts. NBS and Westinghouse researchers recently filed for a patent on the method.

Chemical Engineering Consortia

The NBS Center for Chemical Engineering has formed several different research consortia. By combining the resources of a number of industrial organizations, along with a substantial contribution from concerned government agencies, the cost to each of the companies is relatively small, and the benefit is large.

One consortium, a 4- year program completed just last year, concerned supercritical extraction. This is a process which uses fluids at elevated temperatures and pressures in their critical region to extract or remove specific wanted and unwanted products from a chemical process stream. Supercritical extraction is important in the energy, food processing, and chemical processing industries. It is an especially efficient processing technique, but manufacturers have lacked the necessary data to exploit it fully.

Supercritical extraction is used, for example, for: enhanced recovery of oil from oil fields; removing caffeine from coffee or tea; and extracting lemon oil from lemons and asphalt from petroleum residues.

The consortium developed out of a workshop held at NBS in 1982. The goal of this research was to provide experimental data and to develop accurate models that predict the behavior of systems.

The project was a huge success. Among the results is a state-of-the-art computer code that helps ensure equity for both the buyer and seller in a variety of transactions. For example, this work is being used in the sale of carbon dioxide for tertiary oil recovery. It also is used by designers of chemical processes in the food and chemical process industries.

Consortium members, each of which contributed about $10 thousand a year to support the program included: Cooper Energy, Allied Chemical, Texaco, Gas Processors Association, Monsanto, Amoco, Du Pont, Mobil, Shell, Sohio, ARCO, Ingersoll Rand, Air Products, Phillips Petroleum and the Department of Energy.

Meetings of participants were held twice a year, where our results were disseminated and where consortium members provided us with guidance -- and vice versa.

Out of this grew two new consortia, which will run through 1989. In addition, two other consortia were begun in 1984 and 1985 to address the problems of precise flow-measuring techniques needed to maintain quality control for processing industries as well as to assess fair charges for oil and gas products delivered by pipeline.

Center for Advanced Research in Biotechnology

The Center for Advanced Research in Biotechnology (CARB) is still a relatively new cooperative venture, but one that already promises important results to the emerging biotechnology industry. CARB was jointly established by NBS, the University of Maryland, and Montgomery County (Md.) to provide a unique forum for collaborative research among academic, government, and industrial scientists. CARB's complex now under construction will be one of the world's finest facilities for the determination and analysis of the structure of macromolecules. It will help to radically reduce the time and effort required to determine the atomic structure of proteins and to effectively model and predict their properties. This will help build the foundation for the rapidly emerging fields of protein engineering and rational drug design.

NBS and University of Maryland researchers began collaborating even before ground was broken. Now, industrial firms have joined the effort. CARB is working with Triton Biosciences, a Shell subsidiary, and with W.R. Grace & Co. Arrangements with other companies are pending.

CARB's agreement with a Japanese-owned firm, which runs a research facility located close to CARB and NBS, offers an interesting twist on the question of technology transfer between countries. CARB has an arrangement with Otsuka Pharmaceutical Co. whereby that firm has supplied our researchers with highly valuable genetically engineered human interleukin. Since NBS and therefore CARB has experts in the analysis of protein crystal structures -- an essential step in learning more about the makeup of genetically engineered materials -- Otsuka asked us to analyze the material. We will make the results available to Otsuka -- but we also will make them available to U.S. companies. That will give these firms information on a Japanese company's research product to which they would not ordinarily have access. There is an interesting footnote to this agreement: we will publish the results in English, in the U.S. literature, making the information even more readily accessible to American companies. I only hope they take advantage of this unique technology transfer opportunity.

Other Cooperative Efforts

Some of our other ongoing cooperative research projects with a substantial technology transfer element include:

-- Working with several hundred industry organizations that develop Open Systems Interconnection - conforming products to meet industry and government requirements that will speed the use of computer networks.

-- Developing nondestructive evaluation sensors for steel processing with the American Iron and Steel Institute.

-- Investigating polymer blends for optical and other applications with Eastman Kodak.

-- Determining alloy phase diagrams with the American Society for Metals.

-- Developing test structures for the manufacture of integrated circuits with Westinghouse R&D Center, Martin Marietta, and American Micro Systems Inc.

-- Assessing the relative fire hazards of different materials with the Society of the Plastics Industry, American Textile Manufacturers Association, American Iron and Steel Institute, Carpet and Rug Institute, Manmade Fibers Association, National Association of Bedding Manufacturers, and the International Copper Research Association.

These aren't examples of high-sounding theory, policies, or novel and unproven attempts at getting industry and government to work together. These are real-world projects giving results that are helping the private sector.

We have scores of other examples of successful technology transfer through cooperative work. At last count, we had about 250 active, formal collaborative projects.

We are constantly in search of new partners for research that will help both NBS and the private sector to accomplish their goals. We have published a special brochure that describes many of the opportunities for cooperative research at NBS.

As I look back on what I have said today about our cooperative work with industry, my thoughts go back to 1982, when I wrote an editorial in Science magazine, hoping to give some basic tips from our long experience working cooperatively with industry. At the time it attracted absolutely no attention. I was recently reading that editorial, and it seemed to me to be just as relevant today. With your permission, I would like to submit that editorial for the record, hoping for more attention the second time around.

I would like to summarize some of those lessons that we have learned. As collaborators with industry, Federal laboratories need to:

O consider the commercial potential of their mission oriented research.

O make sure to have the facilities, expertise and dedication to do the job well, or don't try to do it at all.

- do the job on time: industry will not tolerate empty promises or tardy results, and rightly so.

- don't assume the task has to be large; often it is the smaller projects with limited but well-defined objectives which are most useful to industry.

- don't assume the task has to be long-term.

- constantly monitor the direction of the collaborative program and then change it as necessary -- that is, set up spin-off efforts, scale the project up or down as needed.

- always look for new opportunities for collaboration.

- be attentive to detail.

- be flexible.

And by all means,

- be persistent!

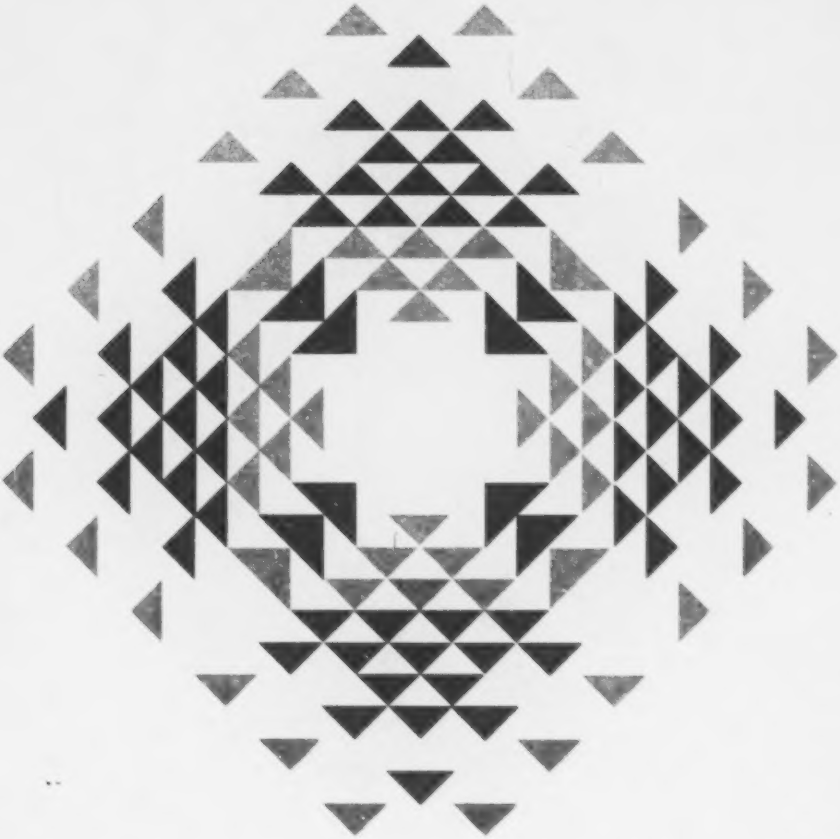
Before I close my remarks, I would like to bring to your attention a program NBS is working on that has an important technology transfer element, the Malcolm Baldrige National Quality Award. This annual award, established under P.L. 100-107, will provide national prestige to as many as six U.S.-owned and located companies in the manufacturing and service sectors which have clearly demonstrated improved quality in their products or services.

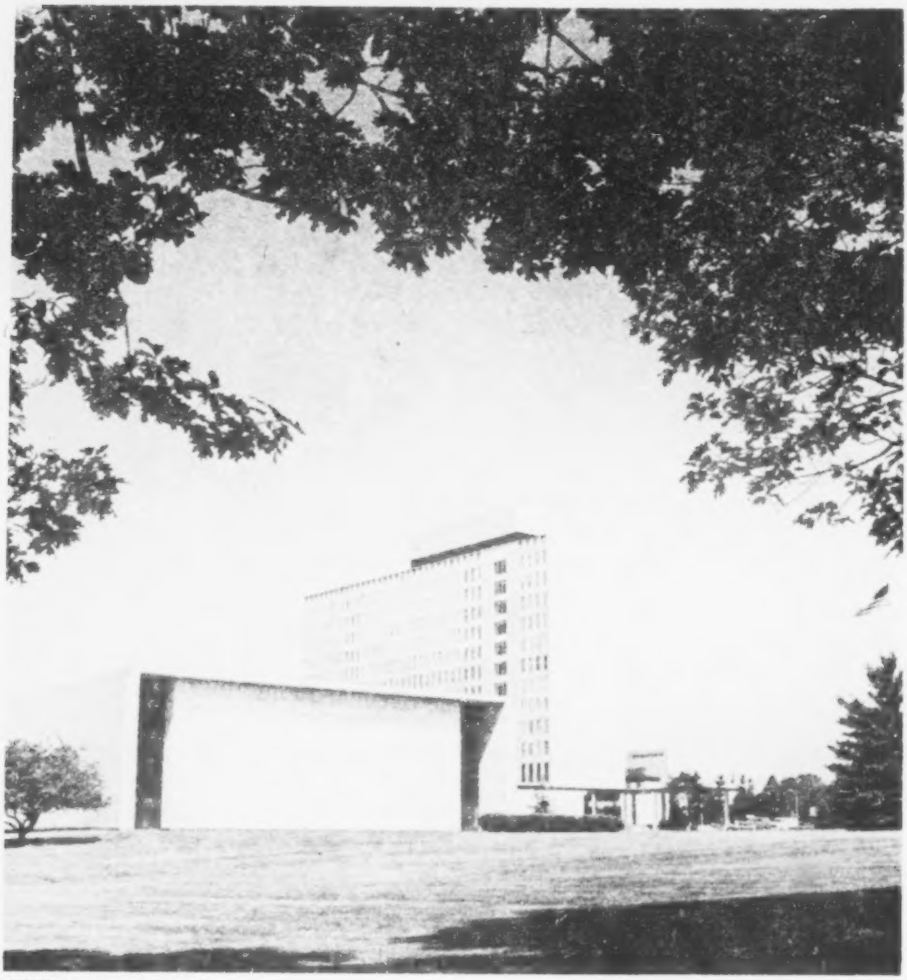
The Commerce Department and NBS in particular are given key roles in administering this award. In addition, the private sector plays an important part, providing funding and performing many of the important tasks needed to develop and administer the award. In setting up this award, we envision a technology transfer effort that will enlist private sector organizations as well as NBS and other parts of the Commerce Department in publicizing the country's quality success stories. The end goal will be to offer U.S. companies specific information that will help them to follow the example of U.S. quality leaders.

Thank you for the opportunity to appear before you, Mr. Chairman. I shall be glad to answer any questions you.

Cooperative Research Opportunities at NBS

U.S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS





NBS Gaithersburg laboratories.

Message from the Director

Our primary goal as the nation's physical sciences and engineering measurement laboratory is to serve industry and science—to make sure our research is helping the nation solve its measurement problems. By doing so, we help industry exploit the nation's science and technology in its quest to compete successfully in the international marketplace.

At the National Bureau of Standards, we found long ago that one of the most effective ways to accomplish this is through cooperative research. Each year more than 900 people from industry, universities, and other government agencies work side-by-side with NBS scientists and engineers on a wide range of research projects including automated manufacturing, biotechnology, computer networking, and mechanical failure of materials.

Because I firmly believe we will best meet today's economic and technological challenges by working together, we are increasing the opportunities for cooperative research here at the National Bureau of Standards. Let me mention just briefly the advantages, as I see them, of collaborative research to both NBS and the cooperating organization.

Researchers from industry, universities, and other government agencies get an opportunity to work with NBS specialists, many of whom are renowned experts in their fields, and to use the Bureau's premier research and testing facilities. They take newly developed technology back to their organizations to be incorporated immediately into new ideas, new processes, and new products. NBS researchers, in turn, learn firsthand the views and needs of Bureau clients and, as a result, we are better able to direct our research to meet these needs.

One of our longest running cooperative projects has been a remarkably successful collaboration with the American Dental Association. Started in 1928, the alliance has resulted in the panoramic x-ray machine, composite restorative materials, and the high-speed turbine handpiece, for example, as well as major contributions to dozens of standards for dental materials and hundreds of scientific papers.

The scope, duration, and structure of our cooperative projects are tailored to the problem to be solved. They can last for a few weeks or a few years and involve one, several, or even hundreds of organizations. Our goal is to solve the problem at hand quickly, efficiently, and effectively.

I invite you to review the research opportunities described in this brochure, and then to call us to discuss the possibilities for collaborative research in an area that is of concern to both of us. By working together, we can facilitate technology transfer, help improve industrial productivity, and strengthen this nation's ability to compete in international markets.

E. Ambler.

Ernest Ambler
Director

NBS chemist Howard Kingston and Lois Jassie, a chemist from CEM Corporation, have designed microwave techniques that can be used to dissolve chemical samples more safely and efficiently than traditional methods.

4

Cooperative Research at NBS

Numerous opportunities exist for scientists and engineers from industrial, professional, trade, and other organizations to collaborate in research at the National Bureau of Standards on projects of mutual interest. To accomplish its objective of supplying the measurement foundation for industry, science, and technology, NBS conducts research in many areas, including advanced ceramics, automated manufacturing, optoelectronics, and biotechnology.

Operated on an annual budget of about $210 million, the Bureau employs a highly skilled staff of some 2,700 at its headquarters in Gaithersburg, Md., and its site in Boulder, Colo. NBS also has extensive research and testing facilities that are available for use in cooperative research, such as a 20-megawatt research reactor, an electron accelerator, a synchrotron ultraviolet radiation facility, a supercomputer, a large-scale structures testing facility, a metals-processing laboratory, a fire research facility, and a computer network protocol testing and evaluation laboratory.

NBS will work with a company, trade association, university, or other government agency to solve problems of mutual concern. One of the most popular ways NBS research and facilities are made accessible to U.S. industry is through the Bureau's Industrial Research Associate Program. Under this program, companies, trade associations, and technical societies pay their scientists and engineers to work in NBS laboratories with NBS researchers on a specific project.

In another type of cooperative venture, companies subscribe to a consortium that provides resources to have NBS solve a specific measurement problem facing the industry. This arrangement has advantages when a complex problem confronts a particular industry and the research is too costly or not possible for individual companies to undertake.

Companies also loan or donate equipment or software to the Bureau when NBS researchers are working on a project that could ultimately improve their products or the way they do business. In such situations, these firms actively consult or advise NBS researchers on the needs and concerns of the industry. In other cases, NBS makes its facilities available to companies for proprietary research on a cost-recovery basis, when equal or superior facilities are not otherwise available.

Described below are a few brief examples of different types of cooperative projects and the results they have produced so far.

Manufacturing Research Facility

The NBS Automated Manufacturing Research Facility (AMRF), a research center for studying fundamental questions affecting factory automation, is one of the largest cooperative programs at the Bureau. Since 1982, 35 companies—large and small—have paid more than 50 of their researchers to work in the AMRF, and about $4.6 million worth of equipment and software has been loaned or donated to NBS by industry for this project. The Navy Manufacturing Technology Program is a major partner in the facility, and the Air Force Intelligent Task Automation Project and other government agencies also have sponsored specific parts of the AMRF effort. In addition, a number of universities have contributed to the project by loaning guest researchers.

Together these researchers are experimenting with methods for getting robots, computers, and machine tools from different manufacturers to communicate and work together in an integrated system through standardized interfaces. Their other primary goal is to find a means for controlling quality in a fully automated factory environment by improving the measurement process.

All of this will give companies, in particular small firms with less than 50 employees, the flexibility to buy equipment from different manufacturers at different times with the assurance that the machines they buy can be made to work together without expensive, custom-designed interfaces. Concepts developed at the AMRF are now being adopted by hardware manufacturers and the U.S. Navy.

According to a study by the Management Collaborative Group of Chapel Hill, N.C., the contribution of the AMRF to the increased use of numerical-control machine tools in U.S. industry will produce a savings to the metalworking industry of between $250 and $760 million per year by 1990.

Chemical Engineering Consortia

NBS recently completed a 4-year research project on the properties of supercritical fluids which was sponsored by a consortium of 14 private companies and the Department of Energy. The goal of this research was to develop accurate predictive models for supercritical fluid mixtures and accurate experimental data that can be used to test and further develop the predictive models. Among the results of this effort is a state-of-the-art computer code to be used in the custody transfer of supercritical fluid mixtures.

Meetings of the consortium participants were held twice a year where research results were disseminated and direction of the project discussed. This effort was judged so successful by the participants that two new consortia were formed from it.

NBS researchers are working on two other consortium-sponsored projects in chemical engineering. One consortium, which is studying the measurement problems that result when a meter is installed too close to a pipe elbow or valve, has 10 firms and the Department of Energy as members. The other consortium has a roster that includes nine companies and the National Aeronautics and Space Administration, all of which are interested in improving the performance of vortex-shedding flow meters.

Collaborative Research in Microwave Technology

To refine techniques for rapidly dissolving samples in closed vessels within a microwave chamber, CEM Corporation, a producer of microwave equipment for research purposes, sent one of its chemists to NBS to work as an industrial research associate with Bureau researchers. As a result of this cooperative project, microwave technology can now be used to dissolve samples—everything from biological specimens such as human bone and bovine livers to botanical, geological, metallic, and glassy samples—more safely and efficiently than traditional methods.

By combining the microwave technique's ability to heat materials quickly with the superior dissolving properties of closed containers under pressure, the NBS/CEM research team has designed a method for breaking down samples that takes less than 10 minutes. Traditionally, using hot plates and open-vented beakers, scientists could expect dissolving times of anywhere from 4 hours to 4 days, depending on the complexity of the sample.

The researchers have produced a database of information that will allow industrial chemists to tailor their own microwave devices for desired results. They are also helping others apply their techniques: So far they have given information and advice to more than 250 researchers from companies, universities, and research laboratories.

Biotechnology Center

In a first-of-its-kind agreement for NBS, the Bureau, The University of Maryland, and Montgomery County, Md., are establishing a Center for Advanced Research in Biotechnology (CARB) to provide a forum for collaborative research among academic, government, and industrial scientists. When the new CARB building is completed in December 1987, it is expected to house state-of-the-art facilities and 100 researchers from NBS, The University of Maryland, industry, and other government agencies and universities.

The goal of the center is to radically reduce the time and effort required to determine the atomic structure of proteins and to model and predict their properties. This research will help build the foundation for the rapidly emerging fields of protein engineering and rational drug design.

Phase Diagram Center

ASM International has raised $4 million as industry's portion of a cooperative ASM/NBS program that will give scientists and engineers more reliable data, in the form of alloy phase diagrams, for designing new and better metal alloys and products in which metal alloys are used. Fifty companies, organizations, institutes and agencies, and hundreds of individuals made contributions to ASM.

Researchers from NBS and industry work in the Alloy Phase Diagram Center, which is located at NBS. ASM and NBS also support individual data evaluation programs in other laboratories. The critically evaluated phase diagrams, which are graphic representations of what happens when two or more elements are combined at various temperatures and pressures, are published by ASM as part of the collaborative effort. Data from the ASM/NBS program are expected to save U.S. firms hundreds of millions of dollars.

Computer Networking Workshops

For the past several years, NBS has been working with industry and standards groups to make it easier for those using computer systems or equipment to communicate with each other through computer networks regardless of who manufactures the individual pieces. NBS has cooperated with the standards groups to develop the needed standards and with industry to implement and test the standards in commercial products for the office and factory.

As part of this project, NBS sponsors a series of workshops for vendors and users to discuss the implementation of the Open Systems Interconnection (OSI) Reference Model. To date, over 200 companies, including most major computer manufacturers, communications carriers, semiconductor companies, factory control system companies, and word processing manufacturers, as well as government agencies have participated in the workshops.

Two successful demonstrations—one at the 1984 National Computer Conference, the other at AUTOFACT '85—of standards for the OSI reference model have resulted. These cooperative activities have now led to the use of new computer network protocols by several hundred companies for manufacturing and office automation.

How to Participate

These examples illustrate the range of cooperative programs that it is possible to establish—from a small, very focused project with limited resources to those in which numerous organizations are contributing to research that will affect an entire industry. If you are interested in working with NBS on a project, large or small, write or call one of the offices listed below or one of the contacts given in the Research Opportunities section of this brochure.

- *Industrial Research Associate Program*

Under this program, which NBS has run since the 1920's, scientists and engineers from industry, trade associations, technical societies, and other organizations work side-by-side with NBS researchers. With their salaries paid by their employers, the associates work at NBS, usually for 1 to 3 years, on a wide range of research including robotics, computer science, advanced ceramics, and nondestructive analysis. For further information, contact the NBS Office of Research and Technology Applications, 301/975-3087.

- *Proprietary Facilities*

While most NBS facilities are available for cooperative research, the Bureau recently opened up selected facilities for proprietary research. NBS makes these facilities available under certain conditions to support U.S. industry in its development of new competitive products and processes. For additional information, contact the NBS Program Office, 301/975-2657.

- *Other Arrangements*

To inquire about other types of cooperative research programs with NBS, such as a consortium or research center, contact the appropriate institute or laboratory.

☐ Institute for Materials Science and Engineering, 301/975-5658: Provides standards, measurement methods, data, and quantitative understanding to aid in improving the processing and performance of metals, polymers, ceramics, composites, and glasses.

☐ National Measurement Laboratory, 301/975-4500: Provides the nation with state-of-the-art measurement services in thermodynamics, transport properties, chemical kinetics, surface science, molecular spectroscopy, and chemical analysis. Conducts research to improve realization of basic physical quantities.

☐ Institute for Computer Sciences and Technology, 301/975-2819: Provides the standards, specifications, measurement and test methods, and technical guidance needed by government and industry to make better use of computer hardware, software, networks, and security.

☐ National Engineering Laboratory, 301/975-2301: Conducts research in engineering and applied science. Studies problems in electronics, manufacturing automation, chemical engineering, the behavior (and prevention) of fires, and the design and construction of buildings.

Research Opportunities

NBS welcomes collaboration with scientists and engineers from industry, universities, and other government agencies on most of its projects. To give those interested in cooperative research an idea of the wide range of NBS programs, a sampling of specific Bureau research projects is described on the following pages.

To discuss the possibility of setting up a cooperative research project in one of these areas, write or call the contact listed. (Unless otherwise specified, all contacts are at the National Bureau of Standards, Gaithersburg, MD 20899.) For general information on cooperative research at NBS, write or call one of the offices listed on page 7.

At the horizontal workstation in the NBS Automated Manufacturing Research Facility, engineer Christopher Stevenson (left) of White-Sundstrand and physicist Howard Harary of NBS discuss the next generation of machine tools.

Analytical Chemistry

Atomic Spectroscopy

Atomic spectroscopy methods are probably the most widely used analytical techniques in industry today. Considerable research is required, however, to keep up with the changing needs of industry. NBS research in atomic spectrometry is focused on several different studies. For example, researchers are working to improve the analytical capabilities of the direct current plasma (DCP) and the inductively coupled plasma (ICP), as well as experimenting with the glow discharge as an atom reservoir. Additional research concerns the use of spark sampling for the direct analysis of solids, the continued development of laser-enhanced ionization (LEI) in flames, and the evaluation of various types of coupled chromatographic-spectrometric systems for improving the accuracy of spectroscopic measurements.

NBS scientists also are developing a series of neutral density filters that can be issued as Standard Reference Materials for verifying the accuracy of the transmittance and absorbance scales of ultraviolet, visible, and near infrared absorption spectrophotometers.

Contact: Robert L. Watters, B222 Chemistry Bldg., 301/975-4122.

Analytical Mass Spectrometry

Analytical mass spectrometry has played a key role in assisting industries, such as the semiconductor industry, which require accurate measurements of trace elements in their raw materials, products, and product containers. Bureau research in inorganic mass spectrometry is concerned with developing analytical capabilities for the highly accurate determination of trace inorganics by stable isotope dilution, the highly precise measurement of isotopic compositions, and the highly accurate measurement of absolute isotopic compositions for the redetermination of atomic weights. This research involves development of instrumentation in spark source, thermal source, inductively coupled plasma source, and laser source mass spectrometry and research in chemical separations at the trace level using ion chromatography and other techniques.

Contact: John D. Fassett, A21 Physics Bldg., 301/975-4109.

Inorganic Electroanalytical Research

Recently, electroanalytical chemistry has had a key role in the development of methods and materials for environmental and clinical determinations, in particular, pH and conductance. While Bureau research interests and activities include most areas of electroanalytical and classical chemistry, current emphasis is on electrochemical detector development, voltammetric and ion chromatographic measurement methods, high-purity assay by coulometric titration, potentiometric measurements in biological fluids, and fundamental studies and measurements in pH and aqueous electrolytic conductance. NBS scientists are giving special attention to the development of novel electroanalytical instrumentation, including computer interfacing. For all these projects, instrumentation is available for accurate pH, potentiometric, coulometric, conductometric, voltammetric, and ion-chromatographic measurements.

Contact: William F. Koch, A225 Chemistry Bldg., 301/975-4132.

Activation Analysis

More than 50 billion chemical analyses are performed annually in the United States. The Bureau helps to ensure the accuracy of these analyses by developing new analytical procedures and improving the reliability and accuracy of present methods. One technique under study is activation analysis, which is a highly sensitive, nondestructive, analytical technique not normally available in most industrial laboratories. In this research, methods of nuclear analysis are investigated utilizing the 20-MW NBS research reactor. Research is performed in all areas of the technique including the capabilities of cold-neutron activation, the use of sample self-consistent (monitor) activation, the determination of new mathematical procedures for the resolution of gamma spectra, the development of prompt gamma activation techniques, and the use of charged-particle activation techniques.

Contact: Ronald F. Fleming, B108 Reactor Bldg., 301/975-6279.

Liquid Chromatography/ Electrochemistry

Liquid chromatography is one of the most widely used analytical techniques in industrial laboratories. While this technique has achieved widespread application, its uses can be broadened even further by improvements in detection methods. The focus of NBS research is the development of novel approaches for the electrochemical detection of organic analytes separated by liquid chromatography (LC). To apply this technique most effectively, it is essential to investigate the electrode reaction mechanisms of the compounds to be detected using techniques such as cyclic and reverse-pulse voltammetry, coulometry, and LC/ultraviolet spectroscopy. Ongoing work focuses on the use of differential pulse and dual-electrode detection, as well as the development of single and array microelectrode detectors. Researchers also are developing new liquid chromatographic separations employing specific chemical interactions including chelation, ion-pairing, charge transfer complexation, and acid-base equilibria.

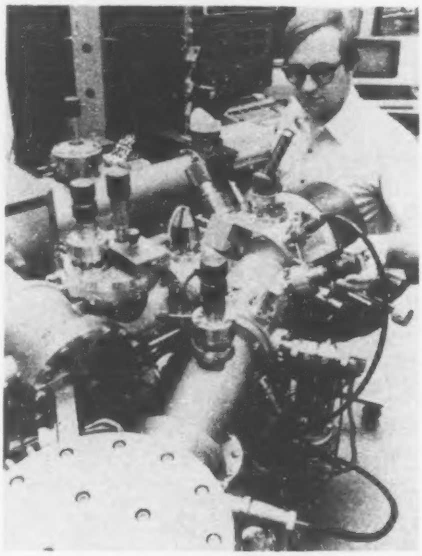
Contact: William A. MacCrehan, A113 Chemistry Bldg., 301/975-3122.

Bioanalytical Sensors

Biosensors are the newest generation of analytical devices having the potential for widespread use in biomedical and industrial monitoring applications. These devices will incorporate the latest advances in biotechnology to provide sensors of high specificity and sensitivity. Biologically derived substances have important application as components of rapid-sensing devices because of their binding specificity, the strength of their interactions, and their potential for use in a wide variety of amplification schemes. Immunological, enzymatic, and receptor-ligand interactions are being explored as the basis for analytical devices.

NBS researchers are employing a variety of optical and electrochemical techniques for detection. Detection can be based on such diverse changes as size and rotational mobility of analytes or binding agents upon interaction, or can be the result of enzymatic activity which occurs due to analyte binding, causing enhanced fluorescence or electrochemical signal. Amplification can be achieved with release to liposome-encapsulated molecules, multi-turnover enzyme reactions, ion-exchange polymer-modified electrodes, and so forth. The combination of high specificity for analytes with efficient amplification provides the potential for extremely sensitive devices.

Contact: Richard A. Durst, A113 Chemistry Bldg., 301/975-3118.



Using a secondary ion mass spectrometry instrument, metallurgist Dale Newbury is able to map the distribution of elements both on and below a sample's surface.

Supercritical Fluid Chromatography

Supercritical fluid chromatography (SFC) in both capillary and packed columns has recently received renewed attention because the process offers several advantages over liquid and gas chromatography for high-efficiency separations of nonvolatile molecules. Potential NBS research in this area would focus on the investigation of the variables that influence the retention, selectivity, and efficiency of SFC systems and on the development of SFC as a useful analytical technique to provide high-efficiency separations of complex mixtures. A packed-column SFC is available and a capillary SFC is being procured to make state-of-the-art measurements. Auxiliary spectroscopic detectors have and are being developed to complement this SFC instrumentation.

Contact: Stephen N. Chesler, 301/975-3102 or Stephen A. Wise, 301/975-3112, A113 Chemistry Bldg.

Liquid Chromatographic Stationary Phases: Retention Mechanisms and Characterization

Liquid chromatography (LC) on chemically bonded stationary phases (e.g., C_{18}, C_8, NH_2, and NO_2) offers unique capabilities for the separation of isomeric compounds or compound classes. However, significant differences in retention and selectivity characteristics, such as relative retention, are observed among commercial phases produced by different manufacturers and even within different batches prepared by the same manufacturer.

One area of NBS research has been directed toward understanding which factors influence LC retention on these various stationary phases to predict, improve, and control the separation selectivity. In reversed-phase LC on C_{18} phases, polycyclic aromatic hydrocarbons have been used as model nonpolar solutes to study retention mechanisms and selectivity. Various physical parameters of these solutes, including size, shape, aqueous solubility, and partition coefficients; characteristics of the bonded phase such as phase type, alkyl chain length, and ligand surface density; and mobile phase characteristics have been studied to determine their influence on retention and selectivity in LC. Investigations have focused on both the physical and chromatographic characterization of these stationary phases.

A variety of methods are available at NBS for physical characterization of these materials, including carbon analysis, gas adsorption surface area techniques, infrared and nuclear magnetic resonance spectroscopy, and small-angle neutron scattering techniques. Currently, Bureau scientists are attempting to develop chromatographic test mixtures to evaluate LC stationary phase characteristics and chromatographic performance. Such "performance" standards would allow the direct comparison of the various LC phases produced by different manufacturers and provide insight into the development of improved stationary phases for specific separations.

Contact: Stephen A. Wise, A113 Chemistry Bldg., 301/975-3112.

Multidimensional and Very High-Resolution Gas Chromatography

Multidimensional (dual column) and very high-resolution (>100,000 plates) gas chromatographic methods offer the analyst an opportunity to perform difficult separations to facilitate species-specific quantitation. These high-resolution techniques are being investigated at NBS to develop highly specific analytical procedures for the quantitation of ng/g organic constituents contained in complex environmental and clinical matrices.

Research in this area focuses on the optimization of multidimensional gas chromatographic experiments in which two capillary columns, each possessing individual and different retention mechanisms, are serially connected by a pneumatic switch. In addition, studies center on the use and development of tailored, very high-resolution capillary columns. An independently controllable, dual-oven gas chromatograph is available for multidimensional research. Additional facilities and equipment include state-of-the-art sample preparation and gas chromatography laboratories, 12 capillary gas chromatographs with multiple specific and non-specific detectors, and a large laboratory information management system (LIMS).

Contact: Stephen N. Chesler, A113 Chemistry Bldg., 301/975-3102.

Microbeam Compositional Mapping

Interpreting the relationship between the physical and chemical microstructure of materials is important in understanding their macroscopic behavior and in extending their in-service performance. Conventional microbeam techniques for elemental/molecular compositional analysis on the micrometer scale, such as the electron microprobe and ion microscope, have been restricted to quantitative analysis at individual locations. Mapping of the distribution of constituents has been possible only at the qualitative or semiquantitative level. However, recent NBS research developments have led to the production of the first true quantitative compositional maps. Quantitative compositional mapping with the electron microprobe has been demonstrated down to levels of 0.1 weight percent, while quantitative isotope ratio measurement in images has been demonstrated with the ion microscope.

Current research activities include extension of compositional mapping to analytical electron microscopy, laser Raman microanalysis, and laser microprobe mass analysis.

Potential projects in this field include applying the compositional mapping instruments to materials characterization problems, developing new techniques for compositional mapping on other microanalysis instruments, and investigating basic topics in quantitative analysis with microbeam instrumentation.

The equipment available for this activity includes a Cameca electron microprobe, a JEOL analytical scanning electron microscope, a JEOL analytical electron microscope, a Cameca ion microscope, a Leybold-Heraeus laser microprobe mass analyzer, two laser Raman microprobes of NBS design, and extensive computer facilities, including a VAX 11/780 computer and a DeAnza image processor.

Contact: Dale E. Newbury, B364 Chemistry Bldg., 301/975-3921

Trace Gas Measurement Techniques

Accurate measurement of gaseous species is of paramount importance to a wide variety of industries in a number of applications ranging from the quantification of pollutant and toxic gas emissions to the quality control of products. The validity of data derived from such measurements is directly tied to the availability of useful gas measurement techniques and to the degree of understanding of their capabilities and limitations. While a variety of techniques have been applied to trace gas analysis, research directed at modifications, innovations, and rigorous assessments of these and new techniques is needed to improve the present state of the art in trace gas analysis. This research is particularly important to the growing requirements for the analysis of specific gas species in multicomponent gaseous mixtures and in the extension of accurate analyses to below the parts-per-million and parts-per-billion levels.

Current NBS research is focused on such trace gas measurement techniques as new detection systems using chemiluminescence, electrochemistry, infrared diode laser systems, capillary gas-liquid and gas-solid chromatography coupled to mass spectrometry, and isotope-dilution mass spectrometry. Bureau scientists also are examining the use of class-specific detectors for gas chromatography and evaluating electronic circuitry to substantially optimize signal and reduce instrumentation noise and drift.

Contact: Walter L. Zielinski, Jr., B364 Chemistry Bldg., 301/975-3918

Nuclear Magnetic Resonance Spectroscopy of Bioorganics

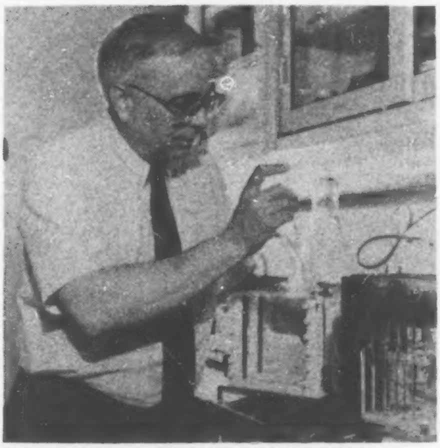
A major task in the industrial production of organic fine chemicals, drugs and antibiotics, and biomolecules is the characterization of the product for both compositional analysis and quality control. Nuclear magnetic resonance (NMR) spectroscopy has proved to be a powerful and widely used tool for these and related purposes.

One NBS program in this area involves the development of new and improved methods for the structural, quantitative, and conformational analysis of materials of chemical and biotechnological importance. The principal techniques that are being investigated include multinuclear, two-dimensional NMR and its combination with multiple quantum methods and distortionless enhancement by polarization transfer (DEPT). A specific goal of this work is the development of new two-dimensional spectrum editing and filtering techniques and their application to structural and conformational characterization via correlations with multinuclear chemical shifts, coupling constants, relaxation times, and nuclear Overhauser effects. This work is conducted at NBS with a high-field (400-MHz) multinuclear NMR spectrometer equipped with a new pulse-programmer (process controller), a high-capacity data acquisition system, an array processor, and an off-line data processing station.

Contact: Bruce Coxon, A361 Chemistry Bldg., 301/975-3135

Protein Characterization by Two-Dimensional Electrophoresis

NBS scientists are using a two-dimensional electrophoresis system to characterize proteins and peptides. At present, they are probing the influence of size, shape, and charge on the migration characteristics in the electrophoretic medium. Well-defined protein "markers," especially of high molecular weight, are required to allow standardization of polyacrylamide gel electrophoretic systems. Charged polymeric materials other than proteins may be considered for markers. Because staining and detection of such markers is of special interest, NBS researchers plan to examine the mechanisms of silver stains with neutron activation techniques.



Research chemist Dennis Reeder is working to improve the accuracy of two-dimensional electrophoresis so biotechnology companies can use the technique to assess their products' purity.

Additional studies will be directed toward understanding the interactions of proteins with metal ions. Image processing by state-of-the-art instrumentation will be implemented in the formation of meaningful databases. As part of this program NBS plans to issue well-characterized mixtures of proteins as Standard Reference Materials (SRM's). These new SRM's will be used to assess the abilities of existing and new electrophoretic techniques for separating and detecting proteins.

Contact: Dennis Reeder, A361 Chemistry Bldg., 301/975-3128

Instability of Compressed Gas Mixtures

Inorganic and organic compressed gas mixtures are employed extensively throughout industry to calibrate equipment used in assessing the quality of products and the effectiveness of emission controls. The stability of these mixtures is critical to their successful use. A number of instances have been noted in which instability has been observed, particularly in mixtures containing low levels of reactive gaseous species, such as nitrogen oxides, sulfur dioxide, and hydrocarbons. The explicit reasons for instability may differ somewhat for different gaseous species, but they are related to at least two possible phenomena: gas-phase reactions and gas-metal interactions with the internal surface of the cylinder.

NBS research is directed at improving the understanding and predictability of both of these phenomena. The techniques involved in this research include those employed in surface science studies and other approaches, such as Fourier-transform infrared spectrophotometry, diode laser and other forms of spectroscopy, mass spectrometry, metal analysis, trace water and oxygen analysis, chemiluminescence analysis, and the use of specifically doped mixtures and homogeneous gas phase kinetics.

Contact: Walter L. Zielinski, Jr., B364 Chemistry Bldg., 301/975-3918

Applied Mathematics

Computational Mechanics

Designing comprehensive software for modeling and database applications in materials science and engineering is the goal of this project. Current research on computer-aided modeling of the behavior of structural materials and components ranges from microscopic feature analysis of fatigue, fracture, phase change, creep, and polymer crystallization to the stress-life prediction of structural reliability of critical components based on mechanical and flaw-detection testing. In these studies, NBS researchers are emphasizing the interplay among the choices of data representation, appropriate physical principles, incisive mathematical and computational tools, and integrated software for graphics and databases. In addition, they are interested in mathematical theories of elasticity, plasticity, viscoelasticity, and so forth, as well as mathematical methods using matrix theory, finite-element algorithms, bifurcation analysis, statistical distribution concepts and sampling theory, and stochastic differential equations.

Contact: Jeffrey T. Fong, A302 Administration Bldg., 301/975-2720.

Measurement Assurance

Quality assurance for physical and chemical measurements and productivity improvement in laboratory operations depend on the development of new statistical methods and models. Current interests at NBS include experiment design for calibrations, robust estimation, time-series analysis, and graphical analysis. In addition, multivariate problems arise in the evaluation of complex electronic equipment. Therefore, estimation of variance components and of statistical tolerance limits for populations with several variance components are being studied.

Contact: Mary G. Natrella, A337 Administration Bldg., 301/975-2854.

Nonlinear Mechanics

Mathematical analysis, in combination with symbolic computation, leads to efficient analytical approximations by computers. Perturbation algorithms applied to nonlinear differential equations, especially in celestial mechanics, result in analytical developments whose complexity grows exponentially with the order of the approximation. Several different avenues are being explored to simplify literal developments generated by perturbation algorithms applied to nonlinear systems. These include the identification of algebraic structures on the domain of the normalization, smoothing transformations to eliminate perturbation terms outside the kernel of the Lie derivative, preparatory transformations of a geometric nature, and the creation of natural intermediaries. Problems currently under examination at NBS are resonances at an equilibrium, perturbed pendulums, and the major theories of celestial mechanics. NBS researchers, using a LISP computer, are focusing their exploration on algorithms amenable to computer automation through symbolic processors.

Contact: Andre Deprit, A302 Administration Bldg., 301/975-2709.

Computational Geometry

Multi-dimensional geometric representations and data structures provide the basis for developing algorithms, software, and computer techniques used to describe, manipulate, and control objects handled in an automated process. NBS applications for this type of geometry include manipulating objects in automated design and manufacturing systems and optimal control of machining and mechanical processes. In addition, techniques of computational geometry are applied to computations with digitized cartographic data and to the display of quasi-crystal structures with icosahedral symmetries.

Contact: Christoph J. Witzgall, A302 Administration Bldg., 301/975-2725 or Sally E. Howe, A151 Technology Bldg., 301/975-3807.

Basic Standards

Vector Algorithms and Mathematical Software

To make effective use of vector computers, new algorithms appropriate to the special architecture of these machines need to be designed and incorporated in high-quality mathematical software for general use. Very successful vector algorithms have been developed for computations in numerical linear algebra (e.g., computation of the discrete Fourier transform), but few are available for combinatorial problems. One area of NBS research is concerned with developing vector algorithms appropriate to the combinatorial problems encountered in molecular dynamics simulations, in particular three-dimensional simulations with very large ensembles of particles. Additional areas include methods for solving highly nonlinear elliptic and parabolic, partial differential equations as well as nonlinear constrained and unconstrained optimization problems and the solution of nonlinear systems of equations. NBS researchers also are working on the solution of integral equations and numerical evaluation of integrals. Software development goals include portable, interactive packages integrating modern graphics with numerical algorithms.

Contact: Francis E. Sullivan, A438 Administration Bldg., 301/975-2732.

Mathematician Sally Howe is developing algorithms and software for robot motion planning that will be used in the Bureau's Automated Manufacturing Research Facility.

Studies of Semiconductor Materials

There is currently tremendous interest in the growth of gallium arsenide (GaAs) semiconductors on silicon substrates because such substrates can provide excellent mechanical strength and thermal properties that are not provided by the GaAs material alone. A major difficulty with growing GaAs on silicon has been the mismatch of lattice constants and the concomitant incorporation of defects. However, new studies show that a better match of the lattice xxx can be achieved if the silicon substrate is cut at a small angle to the crystal plane. To probe the interaction of relevant semiconductor materials with the silicon substrate, NBS scientists are using sensitive, tunable laser sources to detect the individual states of the atoms and molecules as they interact with the growth substrate and growing material. Complete surface diagnostics and ultrahigh vacuum conditions are used in this work. NBS researchers are determining the sticking coefficients and adsorption energies of the individual spin-orbit states of gallium atoms and other dopant atoms plus the effects of vibrational excitation of the arsenic dimers on the growth of GaAs semiconductor materials.

Another Bureau study involves the deposition of thin films of amorphous silicon, which are used in photosensitive devices and in photovoltaic cells. Scientists are examining mechanisms involved in silane discharge and thermal chemical vapor deposition (CVD) production of such films. Mass spectrometry is used to study gas discharge processes, gas chemistry, and surface chemistry and their effect on film growth, character, and quality. Researchers are operating a threshold-ionization mass spectrometer that can detect H and $Si_x H_n$ radicals at densities of 1 part per million of the parent silane gases. The spectrometer also has a threshold sensitivity in the neighborhood of 10^{11} cm^{-3} in the reactor vessel. All electronics, vacuum, and gas handling apparatus necessary for examining rf and dc discharges and thermal CVD under controlled conditions are available as is a pulsed laser for use in studying surface species by laser blowoff.

Contact: Stephen R. Leone, 303/497-3505 or Alan C. Gallagher, 303/497-3936, Div. 525, NBS, Boulder, CO 80303.

Advanced AC Voltage and Current Measurements

Thermal voltage and current converters offer the most accurate and broadband method for measuring ac voltage and current for applications in communications, power generation, aerospace, and defense. Thermal transfer standards are calibrated by NBS in terms of reference converters which have themselves been characterized by reference to the NBS primary standards. The primary standards are a set of special multijunction thermal converters whose performance is known over quite limited ranges of current, voltage, and frequency. Complex, bootstrap methods are used to extend the current, voltage, and frequency ranges. However, because uncertainties expand considerably in those regions remote from the primary standards, NBS is studying new methods and converter designs to reduce significantly uncertainty for these regions. Of particular interest are voltages below 0.5 V at all frequencies and frequencies from 100 kHz to 1 MHz at all voltages. The apparatus available for the studies includes the NBS primary standards with sub-part-per-million (ppm) uncertainty in a core region of parameter space and a number of high-accuracy comparators, both manual and automated, with sub-ppm accuracy capability.

Contact: Joseph R. Kinard, 301/975-4250 or Norman B. Belecki, 301/975-4223, B146 Metrology Bldg.

Laser Stabilization

Many of the most sensitive and sophisticated applications of lasers depend on the laser's spectral coherence, frequency stability, and low-intensity noise. For a number of years, NBS scientists have been working on appropriate laser control techniques in the domain of laser intensity stabilization, laser frequency stabilization, linewidth reduction with active control techniques, and several methods for producing quantitative laser frequency scans. In the latter category are two new systems. One, based on optical sideband production by broadband microwave phase modulation of the laser, allows scans over a ±5-GHz range with inaccuracy below 10 kHz. The other scan technique utilizes a novel interferometer/phase-locked rf system which maps optical frequency change into corresponding phase change of an rf signal suitable for control, stabilization, and scanning. This system is intrinsically free of errors which accumulate over large scans. In combination with a Lambdameter for coarse wavelength identification and a single absorption line used as absolute calibration, for example, NBS scientists can scan a few dozen angstroms with sub-MHz accuracy.

Another NBS system under development works entirely externally to a cw laser to shift the output laser frequency and reduce the intensity in a controlled manner. The first application of this is clearly a box which will sit in the output beamline of any laser and "eat" both frequency noise and amplitude noise in the intrinsic output of the laser. Bureau scientists have demonstrated this function by the combination of an external electro-optic phase shifter and an acousto-optic frequency shifter, which also functions as a fast controlled optical attenuator. Residual noise levels near the values fixed by the fundamental quantum fluctuations have been achieved in laboratory experiments.

Contact: John L. Hall, Div. 525, NBS, Boulder, CO 80303, 303/497-3126.

Study of Atomic Structure of Matter with X Rays

X-ray spectroscopy can provide information on electronic structure and on the local atomic structure of atoms in matter. Bureau scientists have constructed a synchrotron radiation beamline at the National Synchrotron Light Source which provides the highest flux, highest intensity, and highest energy-resolving power of any existing beamline in the x-ray energy range from 1 keV to 5 keV. NBS equipment complements the synchrotron radiation instrumentation. X-ray absorption spectroscopy techniques such as x-ray absorption near edge structure (XANES) and extended x-ray absorption fine structure have been used to determine the atomic structure of metals, semiconductors, polymers, catalysts, biological molecules, and other materials of interest to industry. The Bureau has additional experimental capabilities for x-ray emission spectroscopy, x-ray photoelectron spectroscopy, and Auger electron spectroscopy, which are powerful probes of the electronic structure of solids, liquids, or gases.

The x-ray standing wave technique uses interference between incident and diffracted x rays to determine the precise location of impurities or imperfections within a crystal or at its interfaces. The technique can be used to investigate the location of dopants and imperfections in semiconductors or optical crystals, growth of overlayers on crystals, and the structure of catalysts supported on crystal substrates. In addition, evanescent x rays which penetrate only a few nanometers from an interface can be controlled to study chemical composition in the vicinity of an interface.

NBS scientists recently pioneered a new technique, diffraction of evanescent x rays (DEX), which combines and extends the capabilities of the x-ray standing wave method and experiments based on evanescent x rays. The synchrotron radiation beamline provides an ideal facility for applying these techniques.

Contact: Paul L. Cowan, 301/975-4846 or Richard D. Deslattes, 301/975-4841, A141 Physics Bldg.

Physicist Dieter Hils, at the NBS/University of Colorado Joint Institute for Laboratory Astrophysics, conducts research in the stabilization of laser systems to provide standard sources of monochromatic optical waves. Such devices are of commercial interest for many areas of industrial and scientific research.

Vacuum and Leak Standards

A wide variety of industries depend on accurate vacuum (pressure) and leak measurements for research and development and for process and quality control. As part of its program in basic standards, NBS maintains, or is developing, pressure or vacuum standards from above atmospheric pressure to ultrahigh vacuum and leak or flow standards from 10^{-3} to below 10^{-9} std cc/s. Facilities for this research include five UHV systems, two low-range flowmeters, high-accuracy mercury manometers, pressure and vacuum control systems, and a variety of vacuum, electronic, data acquisition, and data analysis equipment. These facilities and measurement capabilities are used to develop improved measurement techniques and equipment and to investigate the performance of vacuum and pressure equipment, including mechanical pressure gauges, momentum transfer gauges, ionization gauges, standard leaks, and residual gas analyzers. In addition, NBS plans to use this measurement capability to investigate material properties and physical phenomena of fundamental interest.

Contact: Charles R.Tilford, A515 Metrology Bldg., 301/975-4828

Frequency, Time, and Phase Noise Measurement

Advancements in communication and navigation systems require atomic oscillators with increased performance and reliability. NBS has several programs aimed at providing advanced frequency standards which have the potential for benefitting commercial atomic standards. Bureau scientists are currently working on an optically pumped cesium-beam standard which should significantly surpass the performance of standards based on magnetic state selection and detection. Their studies on ion storage and radiative cooling are probing the potential for standards operating at accuracy levels of one part in 10^{15} and perhaps beyond.

Aerospace systems often require extreme phase stability, which has led to a need for high-quality phase noise characterization amplifiers, frequency multipliers, oscillators, and other electronic components. Thus, NBS has initiated a program to develop methods for measuring phase noise in such components over a broad frequency range (into the millimeter range). The work will primarily involve the two-oscillator technique, but other techniques will be studied.

Requirements for synchronization (time) and syntonization (frequency) of broadly dispersed sets of nodes for communication, navigation, and other electronic systems are increasing significantly. Because of the inherent reliability, simplicity, and low cost of using satellite transfer, NBS is studying several possible approaches for using this technique. The excellent performance of the NBS Time Scale and reliable ties to many other international timing centers provide the basis for analysis of the performance of these time-transfer techniques. In addition, the Bureau is equipped with GPS receivers, Earth communication terminals, and automated systems for statistical analysis of the performance of systems.

Contact: Donald B. Sullivan, Div. 724.03, NBS, Boulder, CO 80303, 303/497-3772.

Solid-State DC Voltage Standards

Precision voltage standards based on solid-state references are finding increasing use in dc voltage metrology, particularly in the design and support of high-accuracy digital voltmeters and automated test equipment. To improve the quality of these standards, Bureau scientists are carrying out a research program on Zener diodes and similar devices. They are investigating device properties such as temperature coefficient, short-term noise, long-term stability, and performance under temperature shock and power interruption. The aim of these evaluations is to identify devices suitable for a rugged 10-V transportable standard capable of providing sub-part-per-million (ppm) accuracy when used as a transport standard between laboratories. The effects of temperature extremes, physical shock, and shipping delays on diode output is of special interest.

In another area of research, NBS is producing a stable 1.018-V output derived from a solid-state reference. The researchers are specifically interested in the design and manufacture of low-noise, stable resistors that are immune to temperature shock and power interruption. Facilities are available to test Zener diodes with 0.1-ppm resolution and to manufacture both bulk metal foil and wire-wound resistors. Detailed study of the dependence of device performance on fabrication parameters is possible through high-accuracy measurements referenced to national standards and collaboration with Bureau scientists in several NBS divisions on the fabrication of Zener devices.

Contact: Bruce F. Field, B258 Metrology Bldg., 301/975-4230 or Norman B. Belecki, B146 Metrology Bldg., 301/975-4223.

Automated Mass Measurements

High-precision mass measurements on mechanical balances in industrial standards laboratories are now very slow and labor intensive. Since fully automated mass measurement systems are not yet commercially available, the NBS mass program is developing a low-cost modular system. It will include a balance beam servo-system for automatic data acquisition; automatic modules to probe

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air temperature, pressure, and relative humidity; a thermal "weight-soaking" plate servoed to the temperature of the balance chamber; a robotic weight-changer that can accommodate multiple-weight combinations; and integrated software to control the measurement process and analyze the data with the NBS mass code. Many of these concepts have already been incorporated into a transportable mass measurement assurance package that is now being tested in industrial and state metrology laboratories. A fully automated system will not only reduce the labor cost of mass measurements, but will also minimize the operator and environmental biases that enter the manual measurement process.

Contact: Randall M. Schoonover, 301/975-4216 or Robert D. Cutkosky, 301/975-4214, B160 Physics Bldg.

Temperature Sensor Research

Improved industrial processes and sophisticated scientific research require temperature sensors that cover wider temperature ranges with better accuracy and precision. For example, the degradation of thermocouples exposed to high temperatures for extended periods of time represents a serious impediment to temperature measurements in jet engines, furnaces, and so forth. NBS has several projects under way to test and improve the performance of currently available sensors. These sensors include thermocouples, platinum resistance thermometers, and a variety of cryogenic temperature transducers. The temperature range covered by these projects extends from cryogenic temperatures (0.005 K) to about 1500 °C. For this research, the Bureau has excellent temperature calibration facilities, an automated laboratory equipped to evaluate thermocouples at high temperatures, several laboratories equipped for work on platinum resistance thermometers, and cryogenic laboratories where measurements can be made in the millikelvin range. NBS scientists are planning a series of studies of new materials, new principles, and new techniques to provide uniform and accurate temperature measurements.

Contact: Robert J. Soulen, B128 Physics Bldg., 301/975-4801

Cement and Concrete

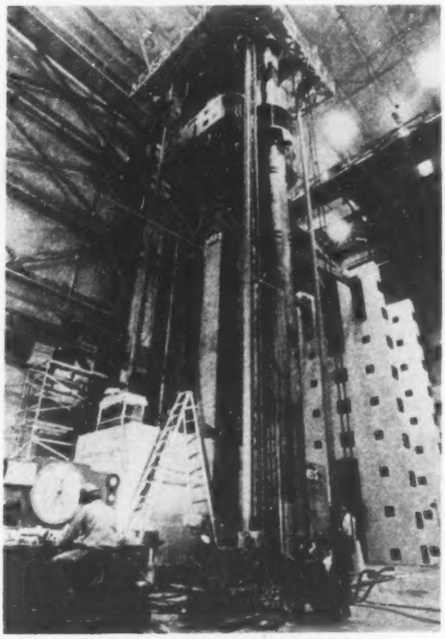
In a strongly computer-oriented program, NBS researchers are seeking to develop an improved understanding of the relations among the chemistry, microstructure, durability, and other factors that affect the performance of cement, concrete, and other inorganic building materials. Current areas of research include mathematical modeling of the development of microstructure in cement hydration and of the effects of microstructure on cracking of concrete; investigations of mechanisms of materials degradation; and development of artificial intelligence systems for optimizing the selection of building materials. Bureau scientists are conducting analytical and experimental research on cracking and the dynamic properties of concrete and other brittle building materials. They are performing chemical and microstructural studies using a variety of techniques, including light microscopy, scanning electron microscopy, x-ray diffraction, and thermal analysis.

Cement hydration research contributes to making concrete a more predictable material. Therefore, NBS is seeking fundamental understanding of portland and related cements and their reactions with water by developing and validating mathematical models based on plausible reaction mechanisms, taking into account such processes as diffusion, nucleation, and growth of new phases. The models, which will probably be run on a Cyber 205 computer, will predict the courses and kinetics of the many reactions taking place during cement hydration and the development of microstructure under a wide range of conditions. Special experimental techniques employed in studying the reactions of cements include, in addition to the techniques mentioned above, microcalorimetry, pore solution analyses, ion chromatography, and Fourier transform infrared spectroscopy.

Contact: James R. Clifton, B348 Building Research Bldg., 301/975-6707

Structural Engineering

Experimental and analytical research is under way at NBS to develop design criteria for steel and masonry structural components subjected to dynamic loads such as winds and earthquakes. The work involves identifying limit states and



This computerized large-scale structural test facility is used to test the performance of full-scale bridge and building components during earthquakes.

establishing criteria to ensure structural safety. In the laboratory, NBS researchers use a unique computer-controlled test facility that can impose forces and/or displacements in three directions simultaneously and a 12-million-pound capacity universal testing machine capable of testing large-scale structural components 60 feet tall. A high-performance computer graphics laboratory including a VAX computer system and specialized graphics-based finite element software is utilized for the analytical work.

Contact: Charles G. Culver, B268 Building Research Bldg., 301/975-6048

Illumination Engineering

To aid in the creation of buildings that operate more efficiently and better meet user requirements, NBS researchers are investigating the interaction between building occupants and illumination/daylighting systems. The work includes developing criteria for illumination quantity and quality and determining the effects of light source color and the color, size, and shape of the object on the performance of visual tasks. In addition, the research involves evaluating both the trade-offs and availability of daylighting as well as illumination controls and their interaction with building heating/cooling systems. The "basic" research laboratory consists of a multichannel electro-optical system that allows light to be delivered to the human eye in an experimentally reproducible manner, while the "applied" research laboratories provide a realistic environment for studying color rendering (distortion) of energy-efficient lighting systems.

Other research projects include daylight prediction computer modeling based on detailed simulation and experimental measurements. Also, the Bureau has initiated an experimental project to determine thermal interactions between lighting systems and HVAC (heating, ventilating, and air-conditioning) systems to provide improved design and evaluation techniques from the standpoint of energy effectiveness, luminous efficacy, and life expectancy of the lighting fixtures.

Contact: Belinda L. Collins, A313 Building Research Bldg., 301/975-6456

Indoor Air Quality and Ventilation Efficacy

NBS researchers are studying techniques for measuring and modeling indoor contaminants, specifically the effect of air leakage and ventilation systems on their levels and movements. NBS pioneered the measurement science for air infiltration by introducing the tracer gas technique. Currently the program has expanded into measurements and computer simulation modeling of various indoor air contaminants, notably formaldehyde and radon. Radon decay and dilution processes have been modeled, and several in-situ measurements are being undertaken to develop techniques to minimize excessive buildup of radon coming from the ground. Bureau researchers have investigated formaldehyde emission rates from pressed particle boards and other building materials to validate a prediction model developed by the Oak Ridge National Laboratory. In addition, NBS is developing comprehensive computer simulation models for predicting emission, dilution, absorption, and convective movement of contaminants in and through buildings with a number of rooms. An advanced gas chromatographic mass spectrometer is used to measure and analyze many indoor contaminants, especially the volatile organic compounds.

Contact: Richard A. Grot, B114 Building Research Bldg., 301/975-6431.

Organic Building Materials

As part of a program to increase the usefulness, safety, and economy of building materials, NBS is conducting basic and applied research to determine the quality and predict the service life of organic building materials such as protective coatings for steel, adhesives, roofing materials, and plastics. Specific areas of basic research include advancing the knowledge of degradation mechanisms, developing improved characterization methods, and designing mathematical models of the degradation processes. The results of this research are then used to derive stochastic models for predicting the service life of these materials. The stochastic models have a basis in reliability theory and life-testing analysis.

Bureau scientists are now using computer analysis of infrared thermographic images for studying the rates of corrosion and the formation and growth of blisters beneath opaque protective coatings. They are also utilizing gel-permeation chromatography, gas chromatography, and spectroscopy to study the mechanisms of photolytic and thermal degradation of poly (methyl methacrylate). In both projects, reliability theory and life-testing analysis techniques are used for predicting the service lives of the materials.

Contact: Larry W. Masters, B348 Building Research Bldg., 301/975-6707.

Refrigeration-Cycle-System Studies

An extensive program to determine the performance of heat-pump and other noncryogenic refrigeration-cycle systems is under way at NBS in both the field and laboratory. The systems being studied include electric-driven, heat-driven (adsorption cycle), and heat-engine-driven systems. An essential part of this program is the development of analytical models that will predict the performance of systems under transient as well as steady-state conditions and with single refrigerants and refrigerant mixtures. These models will be for specific systems, that is, engine-driven or electric-driven, with or without storage, in specific applications such as different buildings and climates. These models will predict the energy performance with various parametric changes, including component sizing.

Contact: David A. Didion, B122 Building Research Bldg., 301/975-5881.

Thermal Insulation

Bureau researchers are devising and improving methods for measuring the heat-transfer performance of thermal insulation and other materials used in the construction of buildings. An essential part of this program is the development of comprehensive analytical and mathematical models that will predict the performance of these materials under transient and steady-state conditions of use. These models will be developed for individual materials and for combinations of materials that are used in the design and construction of building walls, windows, doors, floors, ceilings, and roofs. The work is primarily of a laboratory nature, and excellent new facilities are in place for use in the program. They include a line-heat-source, guarded-hot-plate apparatus that can accommodate specimens up to 15 inches thick with computerized control and data-logging and reduction capabilities, and a calibrated hot-box test facility to measure simultaneously air, moisture, and heat transfer characteristics through a full-size wall 10 feet high and 14 feet wide.

Contact: A. Hunter Fanney, B306 Building Research Bldg., 301/975-5864.

Ceramics

Ceramic Processing

Sintering of ceramics is a complex process that involves the interaction of many different processing variables. The influence of these processing variables on sintering cannot be determined simply by measuring final density or some other end-point property. Chemical composition of the ceramic powders is known to be of major importance and, under certain conditions, can mask effects of most other processing variables. As part of a program on ceramics, NBS scientists are investigating the effect of trace levels of impurities using clean-room processing to produce, compact, and sinter ultrahigh purity ceramics. Compositions will be measured at different stages of the process using nuclear activation analysis (gamma-ray spectroscopy). Results from this program will enhance investigations of other processing variables, including particle size, shape, agglomeration, compaction method, and atmosphere under controlled composition conditions. Such data will lead to better models for microstructure evolution during sintering. Use of predictive models, in conjunction with other ongoing efforts to produce unique compositions and phases, can lead to new advanced ceramic materials, with unique microstructures and properties.

Contact: Edwin R. Fuller, Jr., A258 Materials Bldg., 301/975-5795.

Tribology of Ceramics

NBS is examining the wear and frictional characteristics of advanced ceramic materials with state-of-the-art wear test analysis methods. Studying high-temperature ceramics, especially the type necessary for ceramic heat engines, requires new test procedures and techniques and standardized methodologies. For such research, friction and wear tests may be performed over a wide temperature range with a controlled test environment. Equipment is presently available at the Bureau to test ceramics from 20 to 1500 °C, and a unique high-temperature, controlled-atmosphere ceramic wear test facility that will produce temperatures up to 1500 °C is almost ready for use.

Bureau researchers are also investigating the control of friction and wear by advanced lubricants and lubricant transfer methods. Pre- and post-test analyses include wear debris analysis, profilometry, and scanning electron microscopy (SEM). SEM facilities are used to examine wear tracks and debris.

Contact: Ronald G. Munro, A215 Metrology Bldg., 301/975-3671.

Electro-optic Crystals

Imperfections in highly perfect crystals typically limit their performance in high-technology applications such as optical communications and optical signal processing. In particular, limitations in the perfection of electro-optic and photorefractive materials such as lithium niobate and bismuth silicon oxide have severely inhibited the development of optical switches and modulators. Bureau researchers are investigating crystal perfection at a unique, monochromatic x-ray topography facility at the NBS/Naval Research Laboratory beamlines on the high-energy ring at Brookhaven National Laboratory's National Synchrotron Light Source. The information from current studies, conducted jointly with growers of high-quality crystal, is expected to improve substantially the quality, and hence the performance, of these crystals.

Contact: Bruce W. Steiner, A329 Materials Bldg., 301/975-6122.

Fracture of Ceramics

Bureau scientists are conducting several long-range programs on the fracture behavior of two types of ceramic materials, ceramic composites and polycrystalline ceramics. The program in composites focuses on determining the effects of the fiber/matrix interface on fracture behavior of ceramic matrix composites. The fracture studies on polycrystalline ceramics are exploring the effects of grain boundary compositions and structure on strength and stress corrosion susceptibility as well as the effects of phase transformations on the strength and fracture toughness of piezoelectric and dielectric ceramics. Facilities for these programs include mechanical testing machines for tensile and compressive tests, a microindentation hardness tester, and an environmentally controlled apparatus utilizing double beam configuration for environmentally enhanced crack growth studies.

Contact: Stephen W. Freiman, A329 Materials Bldg., 301/975-5761.

Materials Bioprocessing

Utilizing microorganisms to extract extraneous materials is one goal the steel, mining, minerals recovery, and waste treatment industries have in common. Biological leaching is a low-cost alternative to expensive energy processes. Therefore, NBS researchers are investigating microbiological processes for iron ore and scrap steel beneficiation through biosolubilization of copper and phosphate/silicate minerals, and bioprocessing – leaching and recovery – of strategic metals by mesophilic and thermophilic microorganisms. To develop appropriate processes for each type of extraction, characteristics of such microorganisms must be understood. Thus, NBS is developing and analyzing nondestructive, surface molecular analysis methods including microscopic absorption and emission spectroscopies. In addition, Bureau scientists are using ultratrace molecular speciation methods for solution and gas phase chemical speciation of diagnostic products or intermediates (gas and liquid chromatographs coupled with graphite furnace, flame photometric, and mass spectrometric detectors). Other areas under study include engineering designs, bioreactor systems, and development of standards such as metal sulfide Standard Reference Materials and ore bioleaching test protocols.

Contact: Gregory J. Olson, 301/975-5637 or Frederick E. Brinckman, 301/975-5737, A329 Materials Bldg.

Ceramic Powder Characterization

Improved characterization of particle size, shape, and crystal chemistry of ceramic powders is now recognized as important to the development and production of high-quality ceramics for advanced technological applications. To obtain precise and reproducible measurements of particle characteristics, Bureau scientists are utilizing a variety of instrumental methods, including scanning electron microscopy with image analysis. Theoretical investigations and statistical analyses of data are then used to compare the results of the measurement methods.

The broad NBS program also includes development of x-ray diffraction techniques, reference materials and databases for characterizing ceramic starting powders, and ceramic monoliths. Automated x-ray diffraction instrumentation with position sensitive detectors has the potential for rapid, production-line characterization of both phase composition and material properties of powders and monoliths. Characterization includes determination of powder composition (qualitative and quantitative phase and chemical constituents), glass-to-crystalline ratio, crystallite and particle size, residual stress, lattice parameters, and thermal expansion. Special equipment available for studying the relationships between particle characteristics and processing parameters includes SEM, STEM, DTA-TGA, furnaces with atmospheric control, three automated powder diffractometers with high-temperature stage, coulter counter, BET, sedigraph, and particle-size classifiers.

Contact: Alan L. Dragoo, 301/975-5785; Carl R. Robbins, 301/975-5786; or Camden R. Hubbard, 301/975-6121, A258 Materials Bldg.

Ceramic Surface Analysis

Techniques that probe the surface environment of powders during crystallization and compaction are likely to yield significant information on the link between observed reaction chemistry and product quality. To this end, NBS is investigating Fourier transform infrared (FTIR) and electronic absorption/emission spectroscopies for ceramic surface analysis. Two lines of research in progress exemplify the Bureau's approach and serve as models for further exploration. One project involves silicon nitride powders from various sources that have been examined by FTIR. Compositional purity (Si-N/Si-O ratio) and percent beta phase are easily assessed by this nondestructive technique. The other project concerns a fluorescent tag that has been developed for the siloxy group. The complex formed between the tag and SiO^- on silica gel has been detected by epifluorescence microscopy imaging. This technique is expected to be useful in quantitating the chemistry occurring at crack tips in silica samples.

Contact: Robert A. Faltynek, 301/975-5636 or Frederick E. Brinckman, 301/975-5737, A329 Materials Bldg.

Optical Films Bureau scientists are analyzing the relationship between processing, structure, and properties of optical films grown by electron-beam (e-beam) deposition, e-beam coevaporation, and ion-assisted e-beam deposition. To support industrial development of new optical materials with superior properties such as decreased porosity, decreased stress, greater index stability, and lower absorptivity, these researchers are studying the evolution of film structure starting from nucleation, growth, thin-film adhesion, and thermal properties of films. Characterization capabilities include refractive index by m-line spectroscopy and channel spectra, thickness, absorption coefficients by laser calorimetry, stress by interferometry, thermal diffusivities by photothermal radiometry, x-ray photoelectron spectroscopy, Raman spectroscopy, extended x-ray absorption fine structure, x-ray diffraction, and electron microscopy. New areas to be pursued, with impact on optical signal processing technologies, are epitaxial growth and modulated structures for light-guiding optical films with enhanced electro-optic and nonlinear optical properties.

Contact: Albert Feldman, A329 Materials Bldg., 301/975-5740.

Ceramic Phase Equilibria Ceramic phase equilibria studies at NBS involve complementary research activities in experimental, theoretical, data-evaluation, and compilation aspects of ceramic phase equilibria. These studies include all classes of inorganic materials except alloys. The data-evaluation and compilation work is carried out under the joint American Ceramic Society (ACerS)/NBS program to provide industry and others with a comprehensive database of up-to-date, critically evaluated phase diagram information.

The established, broad-based, fundamental and applied high-temperature chemistry research program examines chemical phenomena temperatures from 25 to above 5000 °C, atmosphere pressures from 10^{-10} to 20 atm, and multicomponent solid, liquid, and vapor systems. New or improved measurement techniques are needed for identification and quantification of species and components present under these conditions. Furthermore, transitional species, such as clusters of atoms or molecules, present a particularly unique measurement challenge. Researchers need to measure such species to be able to understand condensation and surface phenomena on a molecular-level and to develop materials with unique structures and properties. In addition to experimental work, the research involves computer modeling to extend the laboratory-based data to industrial-process conditions.

Contact: John W. Hastie, A329 Materials Bldg., 301/975-5754.

Ceramic Chemistry Bureau scientists are investigating low-temperature synthetic approaches to both oxide and non-oxide ceramic powders and the use of neutron and x-ray scattering expertise in atomic and microstructural studies. Special emphasis is placed on the use of novel chemistry and techniques to solve the problems of generating homogeneous, multicomponent materials with predictable properties. In general, systems currently under study include barium polytitanates, zirconia-toughened aluminas, and silicon carbide-titanium carbide particulate composites.

These researchers are examining the molecular structure of species in multicomponent alkoxide systems, the kinetic aspects of sol-gel reactions, and to the microstructure of product powders and glasses. These studies were undertaken to define key process variables and guidelines for developing practical sol-gel processes. Coupled with powder synthesis and subsequent compaction is the development of in-situ measurement techniques, including small-angle neutron and small-angle x-ray scattering. Such techniques will allow characterization of key fundamental parameters controlling early stages of the material processing. This effort complements nondestructive evaluation (NDE) sensor development so that industry will be able to detect flaws at the very early stages of processing where the raw material can be recovered and treated.

Contact: Kay A. Hardman-Rhyne, A329 Materials Bldg., 301/975-6103.

High-Temperature Reliability of Structural Ceramics

The success of structural ceramics in high-temperature applications, such as heat engines or heat exchangers, depends on the reliability of these materials at temperatures that approach their thermal limit. Because creep-induced cavitation is the primary cause of failure at these temperatures, the characterization of nucleation, growth, and coalescence processes associated with cavitation is essential to establish long-term reliability. Bureau scientists are studying basic processes associated with creep cavitation on a variety of ceramic materials. To develop techniques for predicting component lifetime, they are relating damage accumulation during creep to mechanisms of creep and creep-rupture. This research includes creep and creep-rupture measurements at temperatures as high as 1600 °C, and the use of transmission electron microscopy to evaluate modifications in the microstructure that result in the generation of strength-limiting defects.

Contact: Sheldon M. Wiederhorn, A329 Materials Bldg., 301/975-5772.

Research chemist Joseph Ritter (left) and physical science technician Norman Adams are shown with the reactor they designed for synthesizing advanced ceramic powders at low temperatures.

Chemical Engineering

Separations

Improved energy and manufacturing efficiencies could result from using various techniques to separate and recover desired products from fluid chemical mixtures. To improve separation procedures, the Bureau is creating a science base for a variety of separations. As part of this project, scientists are working in three rather diverse areas. One project involves the aqueous two-phase partitioning of proteins and biomolecules, including measuring mass transfer characteristics and diffusion coefficients and developing mass transfer correlations for classes of biomolecules. In another project, NBS researchers are studying membrane separations of carboxylic and amino acids from reaction products and waste streams using ion exchange membranes. This research includes separating organic compounds from polar solvents and developing models for the transport of weak and strong electrolytes through cation exchange columns. Work in these two areas is expected to impact the commercialization of products in the burgeoning biotechnology industry.

In a third study, Bureau scientists are separating gas using novel/efficient separation methods such as facilitated transport through liquid membranes, while conducting complementary modeling activities. They are currently working on acid-gas separations using ion exchange membranes.

Contact: Subhas K. Sikdar, 303/497-5232, J. Douglas Way, 303/497-5298, or Richard D. Noble, 303/497-3416, Div. 773.10, NBS, Boulder, CO 80303.

Properties of Fluids

Thermophysical properties data are essential for the design and operation of many chemical processes such as supercritical extraction. To obtain these data, NBS scientists are using three new phase equilibria apparatus for studies at elevated temperatures. One has been used to perform VLE measurements on carbon dioxide-hydrocarbon systems and refrigerant-hydrocarbon systems, the second is a dew/bubble point apparatus extending to 800 K, and the third employs a palladium-silver membrane to measure the fugacity of hydrogen-containing mixtures. Four exceptional instruments are available for making PVT, PVTx, and heat capacity measurements on pure fluids and fluid mixtures: an isochoric PVT apparatus, a combined Burnett/isochoric PVT apparatus, a magnetic suspension densimeter for PVT and PVTx measurements, and an instrument to measure constant volume heat capacity. In addition, an apparatus for sound speed measurements is available.

Bureau researchers are also devising techniques to characterize fluids and fluid mixtures when the temperatures, pressures, and times involved can result in reactions during the measurement process. Included in this work is a well-equipped analytical laboratory and specialized apparatus to study reactions.

Contact: Thomas J. Bruno, 303/497-5158; James E. Mayrath, 303/497-3553; William M. Haynes, 303/497-3247; or Gerald C. Straty, 303/497-3502, Div. 774.03, NBS, Boulder, CO 80303.

Radio Frequency Wave Diagnostics of Disperse Systems

The successful processing of paper pulp, flour, coal slurries, and sludge depends on accurate measurements of the percent of solids suspended in water in a pipeline. To help improve these measurements, NBS is studying the propagation of radio waves inside a conducting pipe filled with complex materials. One result of this research has been the successful measurement of the solids fraction in a two-phase water-solid slurry. This was accomplished by measuring the wavelength and attenuation of radio waves in a pipeline utilizing a 32-element antenna array placed along the axial direction. From the known frequency and wavelength the speed of the radio wave, and hence the dielectric constant, can be deduced. By then applying a mixing rule and the dielectric properties of the individual components researchers can determine the solids fraction in a slurry. NBS is extending the project to incorporate systems with axially varying dielectric constants such as adsorption columns and settling suspensions. Other measurements such as polarization rotation in a swirling slurry flow and Doppler shifts due to fluid flow are being planned.

Contact: Adolfas K. Gaigalas, 109 Fluid Mechanics Bldg., 301/975-5941.

Flow Measurement Transfer Standards

The accelerating costs of scarce fluid resources—particularly gas—are producing increased concerns about the performance levels of gas meters. For these reasons, improved flow measurement traceability needs to be established and maintained so that realistic, quantified data are generated on a continuing basis to assure practical gas measurements at satisfactory specified levels of performance. To achieve the desired flow measurement traceability, the Bureau is designing transfer standards to link the performance of calibration facilities to appropriate national reference standards. As part of this program, NBS researchers plan to develop a fluid measurement transfer standard and evaluate its performance.

Because of the importance of these measurements, transfer standards need to be designed so that high levels of confidence can be placed in them and their performance. The new transfer standards will be rigorously evaluated against NBS gas flow calibration standards. This evaluation phase of the proposed program will involve the appropriate range of calibrations to be done on the developed standards so that performance levels can be assured at specified levels.

Contact: George E. Mattingly, 103 Fluid Mechanics Bldg., 301/975-5939.

Fluidized Bed Reactors

NBS researchers are gaining a fundamental understanding of chemical processes in fluidized bed reactors in the areas of bioprocessing and advanced optical measurements at high temperatures. Their work in bioprocessing is aimed at improving the design and operation of liquid fluidized-bed and expanded-bed bioreactors for industrial fermentation processes. To demonstrate the feasibility of monitoring biofilm development in fluidized-bed fermenters, they plan to investigate the effects of hydrodynamics on the development and detachment of immobilized-cell layers from individual carriers, and the effects of these layers on carrier-particle hydrodynamics, using magnetically suspended spheres and other techniques.

Research in the high-temperature area is based on a fluidized-bed reactor that is being adapted for advanced in-situ optical measurements at temperatures up to 1150 °C. The principal advance beyond the state-of-the-art probing of fluidized beds has been the design of an optical probe that allows observations at one or more arbitrarily chosen locations in the interior of the bed. Presently, NBS is interested in studying solids movement in fluidized beds based on the fact that a burning particle generates a distinct signal as it arrives at an optical probe location. The goal of this work is to advance the understanding of the mixing problem in multiphase chemical processes.

Contact: Andrej Macek, B312 Physics Bldg., 301/975-2610.

Thermophysical and Supercritical Properties of Mixtures

Chemical process technology requires an accurate knowledge of various thermophysical properties of pure, polyfunctional chemicals and their mixtures. NBS scientists conduct research on the most important of these properties – equilibrium phase composition, density, and enthalpy. One NBS project deals with developing predictive methods for the properties of chemically dissimilar compounds. Of special interest are those compounds found in gas and coal processing as well as chemical systems. Bureau researchers are planning related experimental phase equilibria studies.

A second project is a combined experimental and theoretical study aimed at developing accurate predictive models for the thermodynamic and transport properties of supercritical solvent mixtures. The work includes PVTx and VLE measurements on mixtures containing carbon dioxide, halogenated hydrocarbons, and similar supercritical solvents. Other experimental work includes the use of supercritical chromatography to measure diffusion coefficients in supercritical mixtures while theoretical studies focus on the application of extended corresponding states to supercritical systems.

Contact: James F. Ely, 303/497-5467, Joseph W. Magee, 303/497-3298, or Thomas J. Bruno, 303/497-5158, Div. 774.03, NBS, Boulder, CO 80303.

Through the use of very thin films and detailed surface analysis, physicist Stephen Semancik and his colleagues have characterized the surface adsorption properties of tin oxide. Such information can be used to improve tin oxide sensors.

Chemical Sensor Research

To understand performance of thin-film and chemical sensors, NBS is performing experimental and analytical research related to these types of sensors. Such studies are expected to improve the accuracy, stability, selectivity, and response of chemical sensors and to stimulate ideas for entirely new measurement techniques. The Bureau's activities incorporate adhesion, oxidation, interlaminar diffusion, surface adsorption and desorption, and phase morphology to uncover mechanisms of chemical sensing. Analytical methods relate the structure and composition of sensing devices to fabricating parameters and performance. Sensors include thin-film thermocouples, fiber optic thermometers, thin-film resistance devices, moisture sensors, pH sensors, and gas detectors. Fabrication facilities include rf and dc sputtering for both alloy and reactive film deposition and gas reactors.

To determine the feasibility of thin-film systems as chemical sensors, NBS scientists are investigating the electronic properties of sputter coatings including dielectric strength, surface conductance, and capacitance. To examine surface-sensitive techniques, they are employing x-ray and uv photoemission, thermal desorption spectroscopy, SIMS, and in-situ electrical measurements to characterize appropriate chemisorptive systems.

Contact: Kenneth G. Kreider, 301/975-2619 or Stephen Semancik, 301/975-2606, B312 Physics Bldg.

Optical Sensing in Bioreactors

Recent advances in molecular biology have led industry to recognize the potential benefit of applying these advances in a diversity of industrial sectors, such as the production of new drugs, food additives, and chemicals and conversion of biomass. However, implementation of these new technologies requires measurement capabilities which do not currently exist. Bioprocesses require a very closely controlled environment, normally realizable only in batch processes. This is mainly due to the complex kinetics of most bioreactions, separate periods of growth and product formation, biocatalyst degeneration, contaminant risks, and mechanical difficulties of handling rheologically complex material. Therefore, development of new on-line measurement techniques is critical for future implementation of bioprocesses. Furthermore, nonintrusive measurement methods are desirable to avoid difficulties associated with sampling, contamination, and long response time.

To help solve some of these problems, NBS scientists are developing optical techniques, especially with the use of tunable lasers, for making nonintrusive, rapid, and selective measurements. The use of fiber optics also permits the development of probes which are sterilizable, can provide measurements with good spatial resolution, and can be multiplexed to provide multipoint monitoring capability. Laser-induced fluorescence is being used to determine characteristics of amino acids, dipeptides, polypeptides, and esters while Raman and resonance Raman scattering will be utilized to provide more species and selectivity. Fluorescence techniques are also expected to provide a powerful tool for cell activity and intracellular kinetics measurements.

Contact: Hratch G. Semerjian, B312 Physics Bldg., 301/975-2609.

Particulate and Droplet Diagnostics in Spray Flames

To minimize the cost of high-price fuel, U.S. industry wants to obtain maximum energy output from fuel combustion. Bureau researchers are tackling this problem by attempting to improve combustion efficiency. To investigate droplet vaporization, pyrolysis, combustion, and particulate formation processes and to delineate the effect of chemical and physical properties of fuels on the above processes, they are studying the dynamics of spray flames. Results of this study will provide an experimental database, with well-defined boundary conditions, for developing and validating spray combustion models. The experiments are being carried out in a spray combustion facility, with a moveable-vane swirl burner, which simulates operating conditions found in practical combustion systems. A combination of nonintrusive probing techniques is being used to obtain comprehensive data on the spray combustion characteristics, including soot particle and droplet size, number density and volume fraction, gas composition, and velocity and temperature fields.

Currently Bureau scientists are focusing their efforts on laser scattering and laser Doppler velocimetry measurements, which are being used to determine the correlation between droplet size and velocity distributions, respectively, in both low-temperature and burning sprays.

Contact: Hratch G. Semerjian, B312 Physics Bldg., 301/975-2609.

Properties of Interfaces

A wide array of experimental and theoretical tools are being applied to obtain practical and fundamental understanding of the structure, properties, and effects of interfaces between fluid phases. NBS scientists are studying a number of problems in this area ranging from the conceptually simple to measure and/or calculate the interfacial tension between a liquid and its vapor, to more complicated ones such as the phase behavior of surfactant mixtures at water-air interfaces, the thicknesses of adsorbed liquid layers at solid-gas interfaces, the stability of foams, and the evolution of mists. Bureau facilities include an automated ellipsometer and an automated film balance, quasielastic light scattering for studying the evolution of mists, an apparatus for measuring foam stability, and simple setups for measuring interfacial tension. Computing facilities include a CDC 855, a Cyber 205 vector processor, software, and experience in simulation of fluids.

Bureau scientists are planning research in several areas. One project will involve applying quasielastic light scattering to the measurement of interfacial tension of liquid-vapor mixtures at high pressure and the measurement of the dynamics of wetting layers. Another project will focus on measuring the permeability, surface viscosity, and surface diffusion coefficients of surfactant layers. In addition, the researchers will test NBS theories developed for the large increase of the surface tension of a liquid-vapor interface when it forms in a confined geometry (such as in a pore within a pellet) and for the large effects of ions on the thicknesses of adsorbed layers. They will also study the evolution of the drop size distribution of simple, but non-trivial, mists comprised of two hydrocarbons suspended in their own vapor.

Contact: Neil Olien, 303/497-3257, Div. 774, NBS, Boulder, CO 80303

Chemical Physics

Chemical Kinetics and Thermochemistry

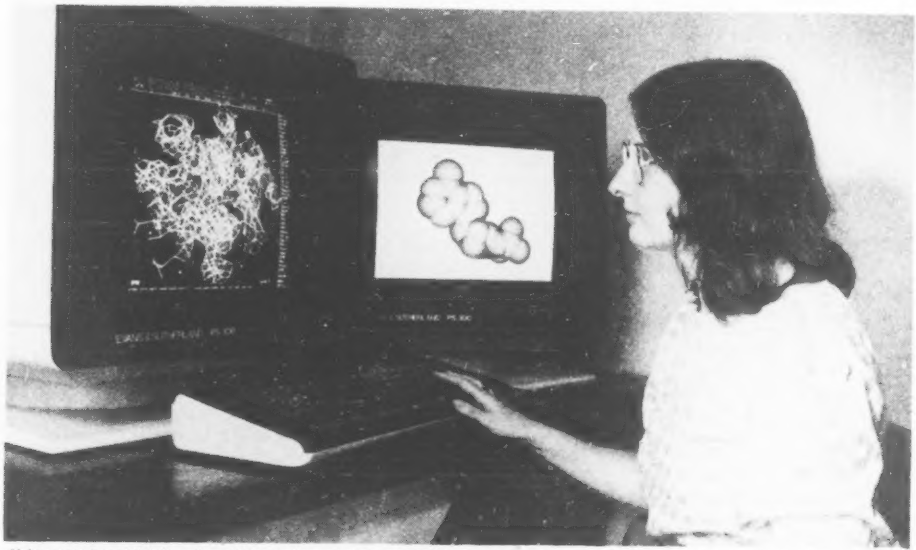
The study of chemical kinetics at NBS has numerous applications, including controlling and monitoring environmental pollution, of interest to industry, energy, defense, and standards experts. Bureau scientists have been determining the kinetics and thermochemistry of industrially important organic molecules, molecular ions, and free radicals. Polycyclic aromatic compounds are important as reactants in coal-conversion processes and as products in virtually all pyrolytic reactions of organic substances. Facilities are available at NBS to determine the elementary rate constants and mechanisms for reactions which control the formation and destruction of aromatic compounds at elevated temperatures. These facilities can be used to study reactions involving polyaromatic free radicals in a variety of physical environments including high-temperature liquids, very low-pressure gases, and graphite surfaces. Complementary theoretical investigations also are possible. Other research involves the thermochemistry of ion-neutral interactions using variable temperature, high pressure, and ion cyclotron resonance spectrometry. In addition, a new laser laboratory incorporating the technique of multiphoton ionization mass spectrometry is available for state-of-the-art detection of free radicals – particularly biradicals. Other chemical dynamics studies can be carried out using picosecond spectroscopy.

Contact: Stephen E. Stein, A147 Chemistry Bldg., 301/975-2506

Biotechnology

To evaluate the properties of important biological building blocks such as proteins and nucleic acids, NBS recently began biothermodynamics studies to evaluate existing thermodynamic data. Biomolecule crystals, which can be purified and grown at the Bureau, can be examined by x-ray and neutron diffraction techniques for single crystals.

NBS researchers have developed quantum chemical computation techniques to calculate how complex systems of organic molecules interact with metal ions in metalloenzymes. Computing facilities include an IBM 4381, an Evans and Sutherland color graphics system for model building, and the NBS Cyber



Using experimental data and sophisticated computers, physicist Irene Weber maps the detailed chemical structure of biomolecules to determine how they can be tailor-made to carry out specific reactions.

855/205 supercomputer. In addition, the thermochemistry of enzyme-catalyzed systems can be studied using a variety of calorimeters including micro-calorimeters designed and constructed at NBS.

Contact: Stanley Abramowitz, B348 Chemistry Bldg., 301/975-2586

Surface Characterization

Surface characterization is now an integral part of many technologies and industries such as catalysis, coatings, corrosion, semiconductors, computers, automobiles, and communications. The Bureau has several surface characterization facilities available, including the use of synchrotron radiation at the NBS synchrotron ultraviolet radiation facility (SURF II) and at the Brookhaven National Synchrotron Light Source. A full complement of surface spectroscopies are available at SURF II and in other NBS laboratories. These can be used to identify molecular species and structures on surfaces. In addition, reaction chambers are connected to some for investigation of surface composition and catalytic reactions. New atom probe field ion microscopes offer high-resolution surface and depth-profile analysis capabilities. Moreover, spectrometers are available at the NBS reactor to perform neutron inelastic scattering and time-of-flight experiments. Neutron scattering is used to study high-area catalytic materials under high-pressure reaction conditions. The sensitivity of this technique to hydrogen makes it particularly attractive for industrial chemical process studies.

Contact: Cedric Powell, B248 Chemistry Bldg., 301/975-2533

Computer Sciences and Technology

Personal Computer Security

The personal computer has become an omnipresent element in today's business and scientific environment. However, as more sensitive and critical information is processed and stored on such systems there is an increasing need for methods to protect that information against unauthorized access or modification. The selection of information security measures, however, should be based on an analysis of the cost of such measures and the resulting reduction in losses. NBS researchers are investigating various technologies that can be employed to achieve additional control and security of information on personal computer systems. Their research involves the identification, analysis, development, and application of these technologies.

While it is desirable to have security mechanisms as an integral part of computer systems, this is not always possible or economical because such mechanisms are often not part of the original system design. Therefore, NBS researchers also are examining the technology available to enhance the security of existing systems. This research involves identifying, analyzing, and comparing security mechanisms used in isolation or combination.

Contact: Allen L. Hankinson, B266 Technology Bldg., 301/975-3289.

Database Testing

To improve the management of information resources, NBS researchers are developing test methods and techniques to be used in evaluating implementations of network database language (NDL), structured query language (SQL), information resource dictionary system (IRDS), and data descriptive file (DDF) for conformance to the emerging federal, national, and international standards. Researchers will attempt to derive a general methodology for designing conformance tests, to use this methodology to generate test suites, and to evaluate the test suites for effectiveness. A prototype implementation of the IRDS specifications will be used in this project. It may be suitable for such tasks as modeling the structure of a standard and for recording what parts of a standard are tested by specific tests.

Contact: Alan Goldfine, A266 Technology Bldg., 301/975-3252.

Public Key Cryptographic Protocols

To help protect data communicated through computer networks, NBS researchers are developing protocols for secure key distribution and secure data transmission using public key algorithms. The protocols will protect keys from initial generation to final distribution to all authorized parties. In designing the protocols, researchers will give special attention to preventing substitution of the keys by unauthorized parties. The protocols will also transmit keys and data within a large computer network with automated communications capabilities. And they will be consistent with those used in the Open Systems Interconnection Reference Model. The project results will be the basis for an NBS publication on public key cryptographic protocols.

Contact: Miles E. Smid, A216 Technology Bldg., 301/975-2938.

Global Communications

In the area of global communications, NBS researchers are attempting to define present and future data communication applications; performance metrics; and characteristics of satellite channels, public data networks, and local area networks. In addition, they will develop simulation and analytical models to permit performance predictions for open systems protocol end systems and various subnetworks. Through various simulation experiments and analytical calculations, NBS researchers will identify areas worthy of future investigation via live experiments. These live experiments will be performed to verify the significant simulation and analytical results.

Contact: John F. Heafner, B217 Technology Bldg., 301/975-3618.

Computer Graphics Testing

NBS is pursuing the development of several graphics standards and is working on related conformance testing and measurement techniques for graphics software. Specifically, Bureau researchers are testing the implementation of the graphical kernel system (GKS), the computer graphics metafile (CGM), GKS for three dimensions, and the programmers hierarchical interactive graphics standard (PHIGS) for conformance to the existing and emerging federal, national, and international standards. The researchers are attempting to derive a general methodology for designing conformance tests, to use this methodology to generate test suites, and to evaluate the test suites for effectiveness. In these studies, they are using the computer graphics laboratory, which contains various computer graphics hardware and computer graphics software systems designed to support standard specifications. An existing test suite for GKS is now available with a FORTRAN interface. Priority is being given to testing methodologies and test suites for PHIGS, CGM, and the conversion of FORTRAN tests for all computer graphics standards to other languages (C, PASCAL, and ADA).

Contact: Mark W. Skall, A265 Technology Bldg., 301/975-3264.

Software Engineering

National and international standards groups are working on standards designed to reduce software engineering problems. As part of this effort, the Bureau has been working on specifications for documents representation. The principal specifications are the office document architecture (ODA) and the standard generalized markup language (SGML). NBS researchers are also striving to adopt a Federal Information Processing Standard (FIPS) for UNIX-based operating system environments. In this project, work is centered in three major areas: development of the technical description of the standard; development of guidance for federal agencies on implementation of the standard; and identification of test methods for testing conformance to the standard.

In addition, NBS is evaluating emerging software engineering workstation technology, specifically the use of stand-alone and interconnected workstations for requirements analysis and design, prototyping, verification, and testing.

Contact: Allen L. Hankinson, B266 Technology Bldg., 301/975-3289

SCSI Verification

Standards development is just the first step toward compatibility of computer products. Test and measurement methods are essential for ensuring that products and systems meet the increasingly complex standards. At NBS researchers are setting up a laboratory in which procedures for verifying the conformance of computer storage peripherals to the Small Computer System Interface (SCSI) standard, X3.131-1986, can be developed. The laboratory is being equipped with a variety of SCSI diagnostic tools and peripherals.

Verification of the conformance of storage peripherals to the SCSI standard is difficult because of the wide range of functionality, features, and options included in the standard. This research will result in a procedure for testing and verifying the conformance of storage peripherals to the standard, which can be published and used by others to test storage peripherals.

Contact: William E. Burr, A216 Technology Bldg., 301/975-2914.

Automated Protocol Methods

The Bureau is designing tools for editing, compiling, and interpreting computer communications protocol specifications. The goal of this research is to advance the state of the art in the application of tools to automatically realize executable implementation of computer communications protocols which are based upon and comply with formal specifications of protocols. As part of this project, Bureau researchers are developing a syntax-directed editor for Estelle and, using the same grammar, devising a portable compiler for Estelle and the supporting runtime libraries.

Contact: John F. Heafner, B217 Technology Bldg., 301/975 3618.

Local Area Networking

To enable computer vendors and users to test their computer systems to make sure they conform to networking standards, NBS has established a laboratory for conducting local area network research and development activities. In this specially designed laboratory, researchers are studying conformance testing, performance measurement, analytic and simulation modeling, integration testing and network management, and control of local area networks. Local area networking technology is necessary for data communication in offices, factories, and laboratory environments where distributed computer network applications are needed. While the interoperability requirements of such networks can lead to unique and expensive communication solutions, the use of standards to achieve product compatibility permits selection of "off-the-shelf" equipment based on cost/performance considerations.

Contact: John F. Heafner, B217 Technology Bldg., 301/975-3618.

Network Security Architecture

To protect computer systems and networks, NBS is developing a comprehensive security architecture consistent with the Open Systems Interconnection (OSI) Reference Model. Cryptographic functions are being implemented in certain OSI layers to provide data secrecy, data integrity, and peer entity authentication. The research will combine the security standards for individual OSI layers into a unified security framework. As part of this project, Bureau researchers will define a common interface for cryptographic algorithms and develop a key management methodology capable of providing keys to the cryptographic functions of any layer.

Contact: Miles E. Smid, A216 Technology Bldg., 301/975-2938.

Mathematicians Elaine Barker and Miles Smid (seated) with computer scientist David Balenson discuss cryptographic techniques for securing network communications.

Electronics and Electrical Engineering

Waveform Recorder Standards

As part of an NBS program aimed at meeting the metrological needs involved in improving signal acquisition and processing systems, Bureau researchers are developing theory, methods, and standards for waveform metrology of conducted signals. In one area, they are conducting the theoretical and experimental research necessary to develop standards for determining the performance of waveform recorders operating nominally below 10 MHz. Techniques for synthesis of precision waveforms and for characterization of those waveforms will be developed. Theoretical studies will be conducted on Fourier analysis, deconvolution techniques, and time-domain analysis. Experimental work is planned in precision pulse generation, static and dynamic testing, and assembly and interpretive level programming for hardware control.

Contact: Barry A. Bell, B162 Metrology Bldg., 301/975-2402.

Antenna Measurements

Research in the Bureau's antenna metrology program results in reliable techniques and standards for measuring key performance parameters of antennas and components used with satellites, Earth terminals, radars, and communications systems. Scientists are now using near-field scanning to characterize microwave and millimeter-wave antennas. The principal emphasis of this work is on developing spherical scanning to accommodate the largest antennas and adapting near-field scanning to anechoic chamber environments, to permit greatly increased use of near-field scanning in industry.

Contact: Allen C. Newell, Div. 723.05, NBS, Boulder, CO 80303, 303/497-3743.

Gallium Arsenide Studies

Research to improve the metrology used to characterize compound semiconductors, especially gallium arsenide, is under way at NBS. Scientists are studying the electrical, optical, and physical properties of gallium arsenide to better understand and characterize presently available device material. They are using a number of measurement techniques in this work, including optical absorption, photoluminescence, infrared and Raman spectroscopy, Hall effect and resistivity measurements, capacitance-voltage profiling, deep-level transient spectroscopy, photoconductivity and photocapacitance, infrared imaging, and x-ray topography and rocking curve analysis.

Contact: Michael I. Bell, 301/975-2081 or Richard A. Forman, 301/975-2047, A305 Technology Bldg.

Integrated Circuit Process Metrology

Theoretical and experimental research on semiconductor materials and process physics at the Bureau is focused on improving understanding of integrated circuit fabrication technology and increasing capability to measure and characterize fabrication materials and processes. Utilizing processing equipment and techniques appropriate to VLSI chip fabrication, NBS scientists conduct experimental studies on issues related to state-of-the-art semiconductor processing in a well-equipped clean-room semiconductor processing laboratory. For example, researchers are studying ion-implantation damage, oxidation growth and interface trap formation, materials effects caused by ion etching, thin-film properties, and plasma and ion-beam chemistry. Other areas of interest include submicron (submicrometer) photolithography, reactive ion etching, beam processing, and chemical and physical vapor deposition.

Contact: Stanley Ruthberg, 301/975-2082 or Gary P. Carver, 301/975-2091, A331 Technology Bldg.

Silicon Characterization

NBS conducts research in semiconductor materials, devices, and integrated circuits to provide the necessary basis for understanding measurement-related requirements in semiconductor technology. As part of this program, NBS scientists are employing electrical, optical, and x-ray methods to study the resistivity, dopant distribution, and concentration of electrically inactive impurities, such as carbon and oxygen, in silicon. They are developing new or improved techniques for two- and three-dimensional mapping of these properties, refining the quantitative aspects of existing methods, and developing methods that are nondestructive. Measurements performed for this research include four-probe, spreading resistance, and capacitance-voltage profiling; Fourier transform infrared spectroscopy; deep-level transient spectroscopy; and x-ray topography.

Electrical engineer Robert Gallawa measures the bandwidth of multi-mode optical fibers as part of an NBS program to develop measurement methods that can be used in fiber development, fiber evaluation in the marketplace, and fiber compatibility in communications systems.

Contact: Michael I. Bell, 301/975-2081 or Jeremiah R. Lowney, 301/975-2048, A305 Technology Bldg.

Magnetics

NBS scientists are developing a basic understanding of magnetic properties of materials and structures to provide a sound basis for measurement techniques. Specifically, researchers are studying precision cryogenic vibrating sample magnetometers, systems based on superconducting quantum interference devices (SQUID's), and laser-based magneto-optical systems. The primary emphasis of this new program is in the field of computer-related magnetics, but work is also under way on the basic physics of magnetic materials, such as spin glasses, and on the measurement of very low-level magnetic effects. In a related program in eddy current nondestructive evaluation (NDE), NBS researchers are developing methods for mapping the very small ac magnetic fields associated with eddy current test probes.

Contact: Frederick R. Fickett, 303/497-3785 or Ronald B. Goldfarb, 303/497-3650, Div. 724.05, NBS, Boulder, CO 80303.

Cryoelectronics

Advances in digital electronics for telecommunications, radar, weapons testing, fusion research, and data processing will demand higher measurement speed than is now possible. The Bureau is now conducting research aimed at exploiting superconducting systems for measurements of extraordinarily high speed, accuracy, and sensitivity. For example, researchers are studying a series array Josephson voltage standard, which is an exciting new approach to simpler, more accurate, and less expensive voltage calibrations and ultra-high-speed analog-to-digital converters and counters, employing as active elements, superconducting quantum interference devices (SQUID's). Their goal is to develop the theoretical and experimental basis for new designs and to fabricate and test these remarkable devices.

Contact: Richard E. Harris, Div. 724.03, NBS, Boulder, CO 80303, 303/497-3776.

Semiconductor Devices

To develop physically sound techniques for characterizing, analyzing, and predicting the operation and performance of semiconductor devices, NBS is designing and improving measurement methods for determining critical device parameters for both VLSI-scale and power devices. Research in device modeling includes two-dimensional silicon MOSFET and GaAs MESFET model development and investigations into the validity of the physical assumptions typically employed in silicon bipolar and GaAs device models. Theoretical research is carried out on the transport of ions and electrons in semiconductors for improved process modeling while experimental research on the nature and characterization of electronic states in oxides and at oxide/semiconductor interfaces is under way. Bureau scientists are developing methods for physical and electrical measurements of device and material parameters which are critical for verifying the accuracy and validity of device models. In addition, they are researching the electrical and thermal properties of power semiconductor devices.

Contact: David L. Blackburn, B310 Technology Bldg., 301/975-2053.

Integrated Circuit Test Structures

Integrated circuit test structures developed by NBS are widely used by the semiconductor industry and other government agencies. These specially designed semiconductor devices can be used to characterize integrated circuit fabrication processes, to evaluate the effectiveness of semiconductor processing equipment, to obtain crucial parameters for device and process models, and for product acceptance. NBS work involves test structure design, mathematical modeling, fabrication, data acquisition, and data analysis. Bureau scientists are conducting research on test structures for random fault detection, yield analysis, and dynamic circuit characterization.

Contact: Loren W. Linholm, B360 Technology Bldg., 301/975-2052.

Electro-Optical Metrology

As part of an NBS program to develop theory, methods, and physical standards for the measurement of electrical quantities in advanced high-voltage/high-power systems, Bureau researchers are developing electro-optical methods for measuring electrical quantities and phenomena. Finite-element code for electric field computation and computer-aided data acquisition and analysis are the focus of theoretical studies. High-voltage ac, dc, and impulse measurements; high-speed cameras; optical multichannel analyzers; and lasers and detectors are addressed in the experimental work.

Contact: Robert E. Hebner, B344 Metrology Bldg., 301/975-2403.

AC Voltage Standards

NBS is conducting both theoretical and experimental research on the synthesis of precision ac waveforms for use in ac voltage standards operating nominally below 10 MHz. The theoretical work includes Walsh functions and Fourier analysis, time-domain analysis, and precision RMS-to-dc conversion techniques. Experimental work involves high-speed, high-accuracy digital-to-analog conversion; precision, high-speed switching; assembly and interpretive level programming for hardware control; and wideband, fast-settling amplifiers.

Contact: Barry A. Bell, B162 Metrology Bldg., 301/975-2402.

Testing Electronic Systems

New strategies are needed for evaluating the performance of complex electronic circuits with the fewest possible tests. NBS is planning a new program which will include theoretical studies of modeling for nonlinear systems, optimization techniques using matrices, statistical and random processes, and artificial intelligence. In addition, experimental work would address test strategies for component and instrument testing; fault diagnosis, function testing, and calibration; and computer analysis using both desktop and supercomputers.

Contact: Barry A. Bell, B162 Metrology Bldg., 301/975-2402.

Raman Scattering

Some of the world's most advanced measurement techniques for the rapid advancement of electrical and electronic technology are available at NBS. For example, a Raman spectroscopy facility is used for light scattering studies of liquids, solids, and gases. Specific research being done at the facility includes chemical and structural analysis of thin films and ion-implanted layers, investigations of impurities and other defects in semiconductors, studies of the structural and electrical properties of semiconductor superlattices and quantum wells, and development of new quantitative spectroscopic methods.

In this laboratory, equipment is available for studies of the pressure and temperature dependence of Raman spectra in the range of 4 to 600 K and up to approximately 100 kbar using a diamond-anvil pressure cell. The laboratory is equipped with a Raman microscope for examining regions several micrometers in size, automated digital data acquisition and processing, variable wavelength lasers, and multiple-grating monochromators.

Contact: Michael I. Bell, A305 Technology Bldg., 301/975-2081.

Gaseous Dielectrics

NBS scientists are developing measurement methods for characterizing gaseous dielectrics for high-voltage power systems. In this study, the theoretical work is expected to address Boltzmann equilibrium statistics, chemical kinetics code, and computer-aided data acquisition and analysis. Experimental work will focus on high-voltage ac and dc tests, gas chromatograph and mass spectrometer techniques for chemical characterization, and partial discharge measurements. Much of the Bureau's work in advanced power metrology is performed in newly completed high-voltage and high-current laboratories. These facilities can generate voltage pulses with peak amplitudes up to 600,000 volts and current pulses with peak amplitudes up to 100,000 amperes.

Contact: Robert E. Hebner, B344 Metrology Bldg., 301/975-2403.

Physicist Gary Carver prepares to inspect a silicon wafer under a microscope in the Bureau's semiconductor processing laboratory.

Fire Research

Flammability and Toxicity Measurement

Bureau researchers are creating ways to measure and characterize the combustibility of furnishings and building materials and the extent combustion products affect living organisms. Typically NBS research focuses on assessing the appropriate applications of the NBS toxicity screening test, evaluating the extent to which a limited number of gases determine the lethality of combustion products, and developing a methodology for predicting soot and gas production in full-scale fires from bench-scale methods. In addition, Bureau researchers are generating a detailed model for the burning of upholstered furniture, devising a measurement methodology to predict the propensity of cigarettes to ignite soft furnishings, and aiding the use of the cone calorimeter in engineering and code applications.

Contact: Vytenis Babrauskas, A363 Polymer Bldg., 301/975-6679.

Fire Simulation

Over the past decade, NBS researchers have developed many computer models of various aspects of fire. Research in this project is aimed at providing the expedient transfer of scientifically based technology from NBS to the professional user community and creates a link between the computer-based activity of the Bureau and others doing similar or complementary work. Researchers develop engineering systems for design application as well as expert systems, collect supporting data and programs, and operate a working and training laboratory dedicated to computer modeling and other fire safety computations.

Contact: Harold E. Nelson, A247 Polymer Bldg., 301/975-6869.

Hazard Analysis

The United States has one of the worst fire records in the industrialized world. The Bureau is providing the scientific and engineering bases needed by manufacturers and the fire protection community to reduce both these losses and the cost of fire protection. One project involves the development of predictive, analytical methods which permit the quantitative assessment of hazard and risk from fires. The Bureau bases these methods on numerical modeling, but also includes hand calculation methods for estimating hazards and production of design curves/tables to be used by architects and engineers. To ensure widespread use, the necessary data must be readily available, and data input and presentation must be in terms readily understandable by the average professional. Thus, the projects include a strong emphasis on state-of-the-art computer graphics and computer-aided design techniques.

Contact: Richard W. Bukowski, B356 Polymer Bldg., 301/975-6879.

Fire Growth and Extinction

Predicting fire growth requires a fundamental understanding of elemental fire processes. Therefore, the Bureau is attempting to develop predictive methods to describe the processes of fire growth and elemental processes of fire growth and extinction as related to gaseous, liquid, and solid fuel combustion and the performance of fire safety systems. Researchers are probing fire growth within a single compartment, the spread of fire to adjoining spaces in multi-compartment structures, and the action of fire suppressants. In addition, they are examining the overall dynamics of the fire scenario and related elemental processes such as ignition, flame spread, pyrolysis, extinction, and fire-related transport processes. For these studies, they utilize mathematical techniques, experimental studies, correlations, and similitude methods to develop predictions.

Contact: James G. Quintiere, B250 Polymer Bldg., 301/975-6863.

Polymer Combustion Research

NBS is conducting research to develop a science base for the gasification and combustion of natural and synthetic polymers, particularly for the more applied fire research activities. For example, NBS scientists are working on the kinetics and heats of combustion for wood, theoretical modeling of thermal degradation of polymers, smoldering research, and detailed degradation mechanisms of polymers.

Contact: Takashi Kashiwagi, B258 Polymer Bldg., 301/975-6693.

Fracture and Deformation

Welding Research

The integrity of welded joints is a primary concern in the design and fabrication of engineering structures. Therefore, NBS is directing research toward improving the fracture resistance of weldments and assessing weld quality by nondestructive evaluation (NDE) techniques. Specific goals of the research are to improve the fracture toughness in the heat-affected zone of steel weldments and in the weld metal of materials for low-temperature service and to better weld soundness through increased understanding of the metal transfer process in arc welding. In addition, Bureau researchers will develop electromagnetic acoustic transducers (EMATs) for ultrasonic inspection of weldments. The research is conducted in the Bureau's welding and NDE laboratories which house equipment for shielded metal arc, gas metal arc, and gas tungsten arc welding; radiographic, ultrasonic, eddy-current, and penetrant techniques for NDE of weldments; acoustoelastic techniques for residual stress measurements; and a precision power supply, high-speed photography, and laser shadow techniques for metal transfer studies. Recently, NBS scientists developed techniques for porosity reduction in aluminum weldments, spatter reduction in gas metal arc welding of steels, flaw size measurements in steel welds using ultrasonics, and residual stress measurements in aluminum weldments.

Contact: Thomas A. Siewert, 303/497-3523 or A. Van Clark, 303/497-3159, Div. 430, NBS, Boulder, CO 80303.

Fracture Mechanics

To ensure the safety and reliability of engineering structures, the Bureau is working to establish a sound technical basis for codes and standards for structures. Specifically, researchers plan to develop a rational basis for material toughness requirements, allowable stress levels, minimum service temperatures, and weld quality standards. NBS capabilities include test equipment with load capacities up to 6,000,000 pound-force, numerical analysis of cracked structures, experimental mechanics, and fractographic techniques. Bureau scientists evaluate materials performance at cryogenic and elevated temperatures, under static and dynamic loading, in corrosive and hydrogen-charging environments, and with random amplitude loading. They have recently completed a fitness-for-service evaluation of steam boilers, a failure analysis of a refinery pressure vessel, dynamic crack arrest tests on structural steels, and a new test method for measuring the fracture toughness of weldments.

Contact: Harry I. McHenry, Div. 430, NBS, Boulder, C0 80303, 303/497-3268.

Manufacturing Engineering

Automated Manufacturing Systems Hardware

Automated manufacturing systems include flexible manufacturing systems and machine tools into which intelligent sensors and controls of the production processes, including the machining itself, have been embedded. To support such developments by industry, NBS conducts several research programs. In manufacturing systems, scientists are investigating generic control systems, full-task programming, data organization, sensor organization, system initialization, and the object-data analogy. In the area of small displacement measurement, researchers are developing transducers with 100-kHz bandwidths for measuring fractional micro-inch displacements over wide temperature ranges for the next generation coordinate measuring machine.

Their efforts in real-time error correction of machine tools are centered on extending microprocessor-based techniques for real-time correction of the kinematic (as well as static) machine errors and tool wear. They are studying transient waves in solids by investigating the origin, propagation, measurement, and direct-and inverse-prediction of micro-mechanical waves in acoustic emission and ultrasonics. Furthermore, Bureau researchers are focusing their studies of transducer fields on the fields produced in solids by electromechanical transducers by modeling and measuring of the fields point-by-point within the solids.

Contact: Donald S. Blomquist, B108 Sound Bldg., 301/975-6600.

Precision Engineering

The precision-engineering industries create and use precision mechanical machines for production applications, such as high-tolerance diamond-turned optical disks as information storage media. NBS conducts research in the design and high-accuracy performance of several types of next-generation machines. Bureau scientists are focusing their studies of thermal modeling of machine tools and coordinate measuring machines (CMM's) on thermal distortions of the geometry of machine tool/CMM's using experimentally-verified finite-element analysis. In robot metrology, researchers are investigating techniques for measuring robot end-effector positioning, including a spherical-system generalization of the extensible ball-bar and a six-transducer laser-tracking approach. In the area of absolute air refractivity, researchers are developing a prototype refractometer based on a heterodyne tracking relative to a stabilized two-frequency laser. Research on advanced coordinate measuring machines is aimed at devising a sub-0.1 nanometer accuracy coordinate measuring machine based on precision mechanical design, high-resolution interferometry, and electron probe techniques.

Contact: Robert J. Hocken, A109 Metrology Bldg., 301/975-3464.

Automated Manufacturing Systems Software

For those industries which create and use computer-controlled manufacturing systems, software systems are the critical element. NBS provides research for software in automated manufacturing systems in several areas. In automated process planning, researchers are investigating data structures for automated process planning, distributed system architectures, machinable-feature identification, and expert systems/machine-learning for manufacturing systems. Researchers are also studying architectures, algorithms, and techniques for real-time adaptive control, scheduling, and optimization of cell- and workstation-level operations for FMS cell and workstation control systems. In addition, for manufacturing systems architectures, they are devising functional models of manufacturing organizations to standard system architectures.

Contact: Howard M. Bloom, A127 Metrology Bldg., 301/975-3509.

Metallurgy

Robotics

The industries which create and apply robotics systems, i.e., intelligent machines which can autonomously operate on the physical environment, range from the makers of industrial robots to the producers of machine vision and other advanced sensory systems. NBS is conducting research on the design of generically applicable control systems for such devices. One project involves image processing architectures. Here, researchers are investigating methods for machine-processing of complex sensory input data employing low-level image processing systems such as PIPE interfaced to high-level symbol-manipulating computer algorithms. Another study concerns world modeling, in which research focuses on methods of constructing computationally efficient world-model representations of three-dimensional object descriptions and geometry of visual images to support, for example, spatial reasoning and predictions of dynamic properties of objects.

In addition, Bureau scientists are studying artificial intelligence for robots by developing techniques to bridge the gap between high-level intelligent planning, decision-making, optimization and goal selection, and low-level servo control. In the area of off-line programming, they are studying group technology, interactive graphics, and object-oriented programming as techniques to overcome the limitations of explicit programming required for robot control.

Contact: James S. Albus, B124 Metrology Bldg., 301/975-3418

Wear of Metals

In many industrial operations, the wear of machine components and materials is one of the principal processes that limits the service life of equipment. At NBS an extensive research program on the effects of wear and erosion on materials is under way to investigate many of these industrial problems. NBS scientists are studying a wide variety of wear modes including adhesive wear, abrasive wear, erosion, galling wear, and lubricated wear. One area of emphasis concerns the effects of materials parameters such as toughness, hardness, ductility, work-hardening characteristics, alloy composition, and microstructure.

As part of this program, NBS scientists are also working with industrial researchers to study the galling wear of alloys used in valves and sliding seals. In this research, scientists are using such characterization techniques as scanning and transmission electron microscopy and various surface analytical methods. Research has shown that high-resolution microscopy can frequently be used to identify the causes of wear, for example, through examination of wear debris particles. NBS has many instruments for conducting wear and erosion experiments under controlled conditions and researchers incorporate standard test methods and equipment where appropriate.

Contact: A. William Ruff, B106 Materials Bldg., 301/975-6010

Synthetic Implant Metals

The use of artificial joints and fracture fixation devices has increased at a rapid rate in recent years. This is due largely to the impressive success of early designs such as the artificial hip joint that used available stainless steel and polyethylene materials. However, as newer types of implants are used for longer times in patients, it has become clear that improved materials are needed for stronger, lighter, more compatible implants. Bureau scientists are studying the mechanical properties and environmental reactions of metals with strong potential for use as implants. They are placing particular emphasis on fatigue life, wear, fretting, processing methods, and surface reactions that occur when the materials are placed in the body. In addition, NBS is characterizing the biocompatibility of these materials by observing cellular growth on metallic surfaces and by studying metal/organic reactions. For this project, NBS researchers are working with several manufacturers in the artificial implant industry to examine the properties and performance of relevant materials. The equipment available for this research includes mechanical testing machines, friction and wear testers, scanning and transmission electron microscopes, and electrochemical apparatus.

Contact: Anna C. Fraker, B128 Materials Bldg., 301/975-6009.

Micromechanical Properties of Materials

The success of many technically advanced materials, such as composite materials, electromagnetic recording tapes and disks, and integrated circuits, depends on their mechanical performance. These materials have refined, complex, and heterogeneous microstructures, but problems arise when they behave as systems and reflect the overall mechanical contributions of components a micrometer or less in size. Generally, hardness numbers from the indentation resistances of pointed tools are used to determine mechanical performance. However, NBS researchers are developing a new and significantly better solution, which is derived from the hardness testing practice. We have expanded this technique with the NBS dynamic microindentation instrument, an apparatus that can be used to determine mechanical performance within sample volumes of less than a micrometer on a side.

Three important innovations have resulted from this project. Two have been completed: indentations can now be described by continuous measurements of applied loadings and penetration depths, and indentations can be made using loading times ranging from hours down to milliseconds. The Bureau's goal, at present, is to obtain conventional uniaxial tensile properties (Young's Modulus, yield stress, and strain) rather than to use hardness numbers. From an industrial viewpoint, the technique aids development of new materials, studies of thermal and mechanical processing effects, and nondestructive examinations of fracture resistance.

Contact: Robert S. Polvani, B112 Materials Bldg., 301/975-6003.

Corrosion Data Program

Corrosion is a major limiting factor in the service life and cost of many products, plants, and equipment. The costs of metallic corrosion to the U.S. economy are estimated to be $167 billion in 1985 dollars, $25 billion of which could be saved by using existing technology. The National Association of Corrosion Engineers (NACE) and NBS have joined together in a collaborative NACE/NBS Corrosion Data Program to reduce these enormous costs of corrosion. The central focus of the Corrosion Data Program is to establish an evaluated corrosion database that researchers can access easily by computer to obtain data in a number of possible graphical or tabular formats. The researchers are developing evaluation methodologies and a prototype database for areas covering thermodynamic and kinetic corrosion data. NBS scientists are emphasizing interactions with industry both to help set priorities for data projects and as a source of corrosion data for the database.

Contact: Gilbert M. Ugiansky, B254 Materials Bldg., 301/975-6022.

Corrosion Measurements

Corrosion has been recognized as one of the major causes of degradation of all kinds of metallic structures, with financial costs well in the billion-dollar range. Since corrosion reactions are of electrochemical nature, electrochemical measurements can give important information about the chemical processes causing the corrosion and the rate of corrosion as well as its forms, whether uniform or localized corrosion. These measurements involve the determination of current and potential and their variations with time; the frequency spectrum of the ac impedance of corroding electrodes; and the detection and analysis of the random fluctuations of electrical parameters.

Electrochemical methods for measuring corrosion rates offer the possibility of following the course of the process in a nondestructive way and assessing the effect of various environmental variables. Other electrochemical techniques can shed light on the kinetics of the corrosion reactions and on the critical factors which may contribute either to catastrophic failures or corrosion prevention. For example, Bureau researchers are now using these methods to investigate the electrochemical processes associated with stress corrosion cracking of brass and copper in ammonia solutions and to examine film breakdown and pit initiation on passive metals.

Contact: Ugo Bertocci, B254 Materials Bldg., 301/975-6017.

Process Control Sensors

NBS researchers are using special facilities to develop advanced measurement methods and standards in support of emerging process control sensors and their application to intelligent processing of materials. Measurement methods available include ultrasound, eddy currents, and acoustic emission. In particular, noncontact ultrasonic facilities have been designed featuring high-intensity pulsed lasers, electromagnetic acoustic transducers, and laser interferometers. Coupled with state-of-the-art materials-processing equipment and expertise, these facilities offer a unique opportunity to ascertain feasibility and develop prototype specifications for a wide spectrum of sensor needs including the measurement of internal temperature, phase transformations, surface-modified layers, porosity, grain size, and inclusion/segregate distributions.

Contact: Haydn N.G. Wadley, A167 Materials Bldg., 301/975-6140.

Rapid Solidification

The rapid solidification of alloys can produce new types of materials unobtainable by conventional means. Because of their special properties, rapidly solidified alloys are being widely investigated and are beginning to be introduced into commercial devices. Equipment is available at the Bureau to study alloys produced by each of the three major kinds of rapid solidification techniques: atomization techniques in which fine liquid droplets are formed and rapidly frozen to produce alloy powder; ribbon techniques in which a very thin liquid stream or ribbon is rapidly solidified; and rapid surface-melting and refreezing techniques in which a directed energy source, such as an electron beam, is scanned across a surface. The emphasis in the NBS work is on measurement and predictive modeling of the rapid solidification processes. Researchers are studying crystalline, metallic glass, and the new quasicrystal alloys recently discovered at NBS. Efforts are under way to apply advanced sensors to an inert gas atomization system to allow feedback and control of this process. Because processing conditions influence alloy homogeneity, microstructure, extended solid solubility, and the production of new alloy phases, control of these features is critical for producing special properties in these new materials.

Contact: John R. Manning, A153 Materials Bldg., 301/975-6157.

Field Corrosion of Metals

The corrosion of metals in natural and man-made environments is very costly to industry and government. For several years, Bureau researchers have been involved in developing methods for measuring the corrosion of metals in field conditions such as steel piling in soil and seawater, electric utility lines in soil, and most recently, steel in concrete. To measure the corrosion of reinforcing steel in concrete bridge decks, NBS scientists have developed a small, portable computer system. With this system, scientists apply electrochemical techniques normally limited to the laboratory to measure the corrosion. This new approach, which allows faster, more accurate corrosion measurements, can be used to evaluate the effectiveness of protection systems in place. The system

Neutron Scattering and Diffraction

has been applied to several bridges in Maryland and will soon be used on bridges in Virginia.

Contact: Edward Escalante, B254 Materials Bldg., 301/975-6014.

Steel Slag Thermochemistry

The U.S. steel industry needs thermochemical databases and models for the design of new or improved steelmaking processes. To design such processes, NBS initiated programs in three areas. Bureau researchers are measuring refractory and slag thermochemical equilibria, evaluating the scattered literature data, and developing computer models relating experimental data to industrial conditions. NBS has unique experimental facilities for measuring key phase equilibria and kinetics.

Contact: John W. Hastie, A329 Materials Bldg., 301/975-5754.

Discussing quasicrystal structures in alloys are (l. to r.) Dan Shechtman, Israel Institute of Technology; Frank Biancaniello, NBS; Denis Gratias, National Science Research Center, France; John Cahn, NBS; Leonid Bendersky, Johns Hopkins University; and Robert Schaefer, NBS. The discovery at NBS of quasicrystal structures in materials challenges a 100-year-old theory of crystallography, and the existence of quasicrystals may make it possible to produce materials with radically different properties.

Neutron Diffraction

Precise information on the crystal structure (arrangement of atoms and molecules) in solids is often a key to understanding or improving the properties of modern materials or creating new ones. Many important materials, e.g., ceramics, catalysts, and rapidly solidified alloys, often can be obtained only in powdered form. State-of-the-art capabilities are in place at the Bureau for measuring and analyzing the magnetic structure of polycrystalline materials by neutron diffraction. The facilities available for diffraction experiments for both powders and crystals include a four-circle diffractometer and a multidetector, high-resolution powder diffractometer, as well as instruments which allow measurements in a single-crystal or energy-dispersive mode.

NBS researchers continue to develop improved methods for accurate structure refinement and for measurement of internal stresses in materials. Currently, a number of industrial scientists are collaborating with NBS staff in neutron diffraction studies of inorganic catalysts, new kinds of ionic conductors for small batteries and fuel cells, improved ceramics for microcircuit substrates and engine components, and high-performance lightweight alloys for advanced aircraft. NBS scientists are also working to determine how residual stress and texture in bulk metals and ceramics affect their application in high-technology products.

Contact: Edward Prince, 301/975-6230 or Antonio Santoro, 301/975-6232, A106 Reactor Bldg.

Neutron Spectroscopy

The vibrational dynamics and diffusion of hydrogen in metals and molecular species in heterogeneous catalysts are studied at the Bureau with inelastic and quasielastic neutron scattering and neutron diffraction. The results of this research reveal the bonding states and atomic scale interactions and diffusion paths in such materials. Recent progress has allowed in-situ spectroscopic studies of hydrogen and molecular species down to 0.1 of an atomic percent. These measurements can provide direct information, for example, on the molecular processes that affect reaction and selective release of chemicals in industrial catalysts and on the local trapping and clustering of hydrogen in metals and semiconductors.

which cause embrittlement of corrosion or changes electronic properties. NBS scientists are working with researchers from several industrial laboratories to study zeolite catalysts. For this research, the equipment available includes three-axis neutron crystal spectrometers and time-of-flight spectrometers for inelastic scattering along with neutron diffractometers, which measure structural and dynamic processes in the time regime from 10^{-10} to 10^{-14} s. Controlled temperature devices are available from 0.3 to 1300 K.

Contact: John M. Rowe, 301/975-6229 or John J. Rush, 301/975-6231, A106 Reactor Bldg.

Small-Angle Neutron Scattering

Small-angle neutron scattering (SANS) is used to characterize submicron structural and magnetic properties of materials in the size regime from 1 to 100 nm. The SANS diffraction patterns produced by structural features in this size regime—for example, by small precipitates or cavities in metal alloys, by micropores or cracks in ceramics, by colloidal suspensions and microemulsions, or by polymers and biological macromolecules—can be analyzed to give information on the size and shape of the scattering centers as well as their size distribution, surface area, and number density. This detailed microstructure information is often a key to the prediction or understanding of the performance or failure modes of structural materials and materials processing conditions.

A number of scientists from the chemical, communications, advanced materials, and aerospace industries are already engaged in SANS research at NBS. Their measurements are carried out with long wavelength neutrons on the 8-m-long NBS SANS spectrometer which utilizes a 65 by 65 cm position-sensitive detector to record data over the entire small-angle region simultaneously. Computer-automated apparatus is available for maintaining samples at temperatures from 4 to 700 K and in magnetic fields up to 20 kilogauss. To extract structural information from the data, the researchers analyze SANS patterns with an interactive color graphics system and related programs.

Contact: Charles J. Glinka, 301/975-6242 or James A. Gotaas, 301/975-6243, A106 Reactor Bldg.

Nondestructive Evaluation

Nondestructive Evaluation for Metal Powder Production

Rapidly solidified metal powders provide a basis for alloys which exhibit, after consolidation, high strength-to-weight ratios, improved fracture toughness and fatigue resistance, unique magnetic properties, and high corrosion resistance. Because neither real-time automated process control techniques for producing rapidly solidified metal powders nor techniques for real-time process control of materials exist, NBS recently initiated a model research project which brings together special capabilities that already exist at NBS. Using a pilot facility for studying the automated production of rapidly solidified metal powders, NBS researchers will develop process models, sensors, and adaptive control techniques for producing rapidly solidified metal powders. Two general categories of sensors are involved: one which measures processing parameters, such as temperatures, pressures, and flow rates; and the other includes nondestructive evaluation sensors which measure or monitor non-intrusively important properties or characteristics of the molten, solidifying, or solid metal powders while they are being produced.

Bureau scientists are designing a new, inert gas atomization system, and they are conducting basic research in solidification science to relate the microstructures formed during solidification to the processing conditions and to the subsequent properties. Research at the completed facility is aimed at combining the process models and the real-time sensors with expert computer systems for adaptive control.

Contact: H. Thomas Yolken, B344 Materials Bldg., 301/975-5727.

Eddy-Current Nondestructive Evaluation

The eddy-current method of nondestructive evaluation (NDE) is capable of detecting extremely minute cracks, pits, and other discontinuities in surfaces and near-surface regions of metals, alloys, and other electrically conductive materials. In addition, it can be used to characterize near-surface properties of thin coatings, films, and bulk materials. However, to characterize such flaws or properties reliably and reproducibly, eddy-current NDE must be made into a quantitative measurement system. Therefore, the goal of an on-going NBS project is to develop measurement methods, calibration procedures, and standards needed for quantitative eddy-current testing. Experimental investigations in several NBS groups are linked with theoretical studies at Stanford University and other related NBS research.

Studies on eddy-current calibration standards, based on electrical-discharge machined notches, have shown that such artifacts must be used with caution. Therefore, comparisons of theory and experiment were recently extended to low-conductivity materials and to real fatigue cracks in order to simulate real test situations more accurately. Results show that magnetic field mapping of eddy-current probes enhances capabilities for characterizing flaws via eddy-current measurements. In addition, field mapping can detect differences in probes of apparently identical construction. Furthermore, field profiles of ferrite core probes, which are difficult to calculate, can now be measured directly. Bureau scientists have developed a new calibration method for uniform field probes and demonstrated an eddy-current technique for monitoring fatigue crack growth. Future studies will also address reflection probes.

Contact: H. Thomas Yolken, B344 Materials Bldg., 301/975-5727.

Using electrohydrodynamic atomization, metallurgist Stephen Ridder produces rapidly solidified alloy powders.

Polymers

Composites Processing

Fiber-reinforced composites offer major advantages, particularly versatility in processing combined with high strength and stiffness at low weight. Continuation of the current growth in the production of these materials, however, is hindered by a need for more rapid and reliable processing. For this reason, the NBS program is aimed at developing new measurement tools to study the reactions associated with processing and the use of these methods to understand the relationships among processing parameters, the microstructure of the fabricated materials, and their performance properties. Such scientific understanding will facilitate both advances in processing methods and implementation of on-line control and automation. The development of this understanding requires researchers to monitor the materials during the curing process to observe simultaneously chemistry, morphology development, flow, molecular network formation, build-up of residual stresses, interfacial effects, and wetting and spreading.

The NBS program currently has 10 different spectroscopic, dielectric, thermal, and mechanical techniques available for cure monitoring and others under development. This diversity of tools provides a unique capability both for evaluating and calibrating new measurement methods and for analyzing model thermoset systems. For example, through cooperative projects with NBS, several industries have selected and developed monitoring methods for their particular problems.

Contact: Donald L. Hunston, A207 Polymer Bldg., 301/975-6838.

Polymer Structure

Knowledge of the relationships between mechanical properties of polymers and polymer structure is important to the design and processing of materials for optimal performance. Therefore, the Bureau is studying semicrystalline polymers, polymer glasses, elastomers, molecular composites, and fibers to develop improved models of mechanical behavior, characterize structure from the atomic to fine texture level, and elucidate relationships between mechanical performance and structure.

A wide variety of techniques is used at the Bureau to characterize the structure of polymers in the solid state. Nuclear magnetic resonance spectroscopy is utilized to determine molecular orientation, molecular dynamics, and microstructure on the 1- to 10-nm scale. Microstructural information is deduced from C-13 lineshapes obtained with magic angle spinning or by proton "spin diffusion" experiments in which domain-size information is inferred from the rates at which proton magnetization diffuses in the presence of magnetization gradients. Fourier transform infrared spectroscopy is applied to determinations of molecular architecture, orientation, and molecular processes, such as measurement of the amount of chain scission associated with mechanical deformation of polymers. Optical and electron microscopic studies of polymers elucidate microstructural features, including spherulytic morphologies, lamellar texture, fiber structures, and crystallization habits. To examine the relationships between mechanical performance of polymers and fine structures, NBS scientists are investigating the morphological changes that polymers undergo when they are deformed. Wide- and small-angle x-ray diffraction techniques, which include the use of position sensitive detectors, are also employed in these investigations.

Contact: Bruno M. Fanconi, A305 Polymer Bldg., 301/975-6770.

Dental and Medical Materials

Modern dental and medical materials utilize numerous substances in an array of combinations. NBS has a comprehensive program that is aimed at increasing basic understanding of the causes for failure or poor performance of these materials, proposing and testing new material systems, and transferring the resultant science and technology to industry. The program has the active participation of researchers from the American Dental Association, the National Institutes of Dental Research, dental industries, and universities.

Researchers are working in a number of areas. For example, in a tribology study, scientists are examining wear and degradation of materials in various environments, and in a bioadhesion project, they are making new monomers for adhesion to tissues. In addition, improved resins are being synthesized to produce polymers that have improved properties such as wear resistance, higher strength, resistance to oral fluids, or x-ray opacity.

In an effort to improve the strength of dental systems, different combinations of materials are being designed and tested. They include ceramic-metal, resin matrix composites, metal-cement, cement-tooth, and composite-adhesive-tooth materials. To improve the systems, Weibull statistical analysis is employed to identify the weakest links. Finite element analysis can be applied to define stress states within systems.

In the area of precision metal casting processes, researchers are using strain gauges to monitor changes in dimensions of investment patterns at pattern sites. A unique casting monitor has been designed that could also be used for rapidly solidified alloys.

Contact: John A. Tesk, A143 Polymer Bldg., 301/975-6801.

Electrical Properties

NBS is conducting a number of studies on the electrical properties of polymers. The research is focused on dielectric measurements, fundamentals and applications of piezoelectric and pyroelectric polymers, measurement of space charge distribution within polymer films, and ionic conduction in solid polymers. In the area of dielectric measurements, Bureau scientists have developed instrumentation and data analysis which can measure the dielectric constant and loss of polymer films over a frequency range of 10^{-3} to 10^{5} Hz in less than 30 minutes. This makes it feasible to follow changes in the dielectric spectrum as a function of time, processing conditions, or other parameters.

The toughness, flexibility, low dielectric constant, and an acoustic impedance close to water make piezoelectric polymers ideal for many transducer applications. NBS staff have considerable experience with the fundamental properties of polymers such as polyvinylidene fluoride and its copolymers and can work with industry to develop transducers for novel applications or assist in measuring the properties of new piezoelectric polymers or composites.

Bureau scientists have designed instrumentation and data analysis to measure the charge or polarization distribution across the thickness of polymer film by analyzing the transient charge response following a pulse of energy on one surface of the film. This technique has been used to detect the presence of non-uniform electric fields in the poling of piezoelectric polymers and is currently being used to investigate the role of space charge in the dielectric breakdown of polymer insulation.

Ionic conduction in polymers has potential application in polymeric electrolytes for high-energy density batteries. The dissolution of salts in polymers and their effect on ionic conduction as well as other polymer properties are being studied by a variety of techniques including thermal analysis, x-ray diffraction, optical microscopy, and impedance spectroscopy.

Contact: George T. Davis, B320 Polymer Bldg., 301/975-6725.

Molecular Networks

Thermosets are used extensively in numerous practical applications, especially polymer-based composites. However, knowledge of the basic structural entity of the thermosets, i.e., their molecular network structure, is very limited. Therefore, Bureau researchers have developed a neutron scattering technique that can be used to quantitatively determine such characteristics of the network as the average distance between crosslinks, the rigidity of the network, the molecular weight distribution between crosslinks, and the topological heterogeneity of the network structure. Current NBS research focuses on developing correlations among chemical compositions, processing conditions, and resulting network structure for epoxy-type polymers. To establish processing-structure-property relations, these materials are then evaluated to determine performance properties such as fracture behavior. The neutron scattering technique is also being used to study how the molecular network deforms when the material is placed under load. These studies can directly benefit industries by providing guidelines for designing and processing polymers for optimum performance.

Contact: Wen-li Wu, A209 Polymer Bldg., 301/975-6839.

Takshiro Sato, a guest scientist from Osaka University, Japan, uses the temperature-jump light scattering technique to record the phase separation behavior in molecules.

Small-Angle X-Ray Scattering

Small-angle x-ray scattering (SAXS) can be used to characterize structural elements of polymers, ceramics, and metals in the 1- to 100-nm size range. The Bureau has successfully used this technique to study phase separation, crystallite morphology, molecular dimensions, void formation, pore characteristics, and many others. A state-of-the-art, 10-meter SAXS facility has been constructed at NBS for such studies, and it is available for cooperative research. This SAXS facility uses a 12-kW rotating anode source, pinhole collimation, and a two-dimensional position-sensitive detector to provide high resolution and simultaneous recording of all scattering data over the entire small-angle region. In addition, a computer-assisted interactive data reduction and analysis program is available with color graphics display for the two-dimensional image. Structural and dimensional information can be extracted using various available model analysis and curve-fitting procedures.

Contact: Charles C. Han, B208 Polymer Bldg., 301/975-6772.

Product Standards

Polymer Blends

Blending polymers has become an effective method for producing high-performance engineering polymers. The fundamental data required to design a manufacturing process include the equilibrium phase diagram, the energetic interaction parameter (compatibility) between the blend components, diffusion coefficients, and the interfacial tension. At NBS small-angle neutron scattering has been used to measure the interaction parameter and phase diagram of polymer blends. NBS scientists have developed forced Rayleigh scattering and temperature-jump light scattering techniques to measure polymer-polymer diffusion and other parameters which control phase separation kinetics and morphology.

Currently, Bureau researchers are testing various kinetic theories of phase separation and late-stage coarsening and studying the control of morphology and mechanical properties of microphase-separated polymer blends. As part of this program, they are working with industry to study the homogenization and phase coarsening of rubber blends.

Contact: Charles C. Han, B208 Polymer Bldg., 301/975-6772.

Fluorescence Monitoring

Bureau researchers are evaluating fluorescence spectroscopy, which is used to characterize the structural and dynamical properties of polymer molecules. For example, fluorescence quenching is employed to monitor the uniformity of mixing in polymer blends and in particle-filled polymer melts. In addition, excimer fluorescence is utilized to monitor the cure of thermosetting resins, while fluorescence anisotropy is used to monitor the non-Newtonian flow of polymer solutions and melts. At NBS, the measurements are carried out with a spectrofluorimeter and a nanosecond spectrofluorimeter. In combination with optical fibers, which are used to get the exciting light into the interior of a composite part, the fluorescence techniques are attractive for process monitoring of composites.

Contact: Francis W. Wang, B320 Polymer Bldg., 301/975-6725.

Laboratory Accreditation Program

To help fulfill the needs of laboratories, industry, governmental regulatory agencies, purchasing authorities, and consumers for reliable laboratory testing, NBS operates the National Voluntary Laboratory Accreditation Program (NVLAP). NVLAP is a voluntary system for assessing and evaluating testing laboratories and accrediting those found competent to perform specific test methods or types of tests on products and materials. Through this program, laboratories are accredited for testing a variety of products, including telecommunications equipment, thermal insulation, and radiation dosimeters.

To establish a laboratory accreditation program, NBS works closely with the appropriate industry to develop the technical requirements and documentation needed for the accreditation process. For example, NBS sponsors public workshops to obtain technical guidance from experts in related industry, government, and standards-developing organizations. NBS also works with industry to design proficiency testing requirements, including selection of test methods for which proficiency testing is necessary and appropriate, the frequency of proficiency testing "rounds," and the artifacts to be tested.

Laboratories interested in receiving accreditation are sent a LAP-specific handbook that contains the generic administrative and operational requirements for accreditation as well as the specific technical requirements for accreditation and a set of critical elements which defines those aspects of each test method that an assessor must consider in determining the laboratory's competence. In addition, the laboratory receives application forms and instructions for providing essential information on laboratory ownership, management, key personnel, scope and operation, test method selection, instrumentation and facilities, and other relevant information.

Contact: Harvey W. Berger, A531 Administration Bldg., 301/975-4017.

Radiation Research

Accelerator Research

The NBS accelerator research program is aimed at developing advanced particle accelerators for applications in nuclear physics, free electron lasers, inertial confinement fusion, and dosimetry. The major focus of this NBS program at present is to establish the feasibility and provide the technology needed for cw accelerators by designing, constructing, and evaluating the performance of a 200-MeV continuous-beam racetrack microtron (RTM) using a room temperature rf accelerating section. In addition, NBS scientists are attempting to modify this racetrack microtron for use as a free-electron laser driver.

To improve industrial applications of particle accelerators, NBS scientists are interested in working with industry researchers to evaluate performance and optimize the RTM design, to design and develop high peak current and high brightness injectors, and design and develop free-electron lasers using the RTM as a driver.

Contact: Samuel Penner, B119 Radiation Physics Bldg., 301/975-5601.

Autoxidation/ Antioxidants

The kinetic and mechanistic aspects of autoxidation in foods, organic materials systems, and other biochemical systems; the design of appropriate antioxidants for the prevention of the deleterious effects of oxygen; and the extension of the lifetime of chemical and biochemical systems are important to many food, drug, and medical industries. Wide-ranging NBS research involves investigations in these general areas: the free radical chemistry of organic systems and biochemicals susceptible to autoxidation and free-radical mechanisms and reaction rates of antioxidants, particularly in the case of key components of foodstuffs and other life-supporting substances. Scientists are studying the effects of parameters such as oxygen pressure, temperature, additives, and concentrations on the optimization of these parameters and the development of products less sensitive to oxidation.

NBS researchers are seeking industrial collaboration in the analysis of short- and long-term intermediate species in pulse-irradiated oxygenated organic and aqueous solutions; derivation of kinetic data and unraveling of auto- and radiation-stimulated oxidation processes; and design of new antioxidants as protective agents against food spoilage, carcinogenesis, atherosclerosis, and nitrosamine formation in foods. Kinetic and analytical chemical technologies, such as GC/MS, HPLC, spectroscopy, chromatography, electrophoresis, and ESR spectroscopy; high-intensity gamma-ray sources, pulsed- and continuous-beam electron accelerators; and various organic-chemical analytical equipment are available.

Contact: Michael G. Simic, C206 Radiation Physics Bldg., 301/975-5558.

Industrial Radiologic Imaging

Imaging by use of penetrating radiation is one of the most powerful investigative techniques available to industry for maintaining or improving the quality of products. Designers are now aware of this and are creating components which facilitate such nondestructive testing. Research is under way at NBS that will allow better quantification of the radiographic images. Particularly relevant to image evaluation are computer-based systems that permit pseudo three-dimensional images and the implementation of image processing on these or traditional images in real time or near real time.

This research focuses on a number of areas, including image processing for improved imaging of low-contrast or noisy images; adoption of tomographic equipment to industrial needs and measurement of the performance characteristics of such systems; and development of reliable techniques for image storage and retrieval. For these projects, available equipment includes x-ray sources, low-energy electron accelerators, and gamma-ray sources as well as state-of-the-art radiologic imaging devices.

Contact: Robert C. Placious, C215 Radiation Physics Bldg., 301/975-5579.

Food Irradiation Chemistry

The use of irradiation as a food preservation technique has made research into the chemistry of food processing by ionizing radiations, such as gamma rays and high-energy electrons, important to food industries. NBS is addressing these concerns by studying chemical changes induced by irradiation processing of food

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components including proteins, fats, sugars, and vitamins. In one project, researchers are selecting radiolytic products which could be used by food processors as indicators to determine whether foods have been irradiated. Other investigations compare thermal and irradiation food processing chemistry and the effect of irradiation processing parameters, such as dose rate and temperature, on food chemistry and quality. Researchers work closely with the Food and Drug Administration and the United States Department of Agriculture to obtain up-to-date information about regulatory and safety requirements for foods and food processing and associated quality control measurements.

Specific areas in which cooperative research is encouraged include kinetic and steady-state analyses of radiolytic products in food components, comparison of energy absorption mechanisms in foods, design of post-irradiation quantitative and qualitative analyses of various foods and their components, and development of food component Standard Reference Materials. Sophisticated analytical techniques such as GC/MS, HPLC, spectroscopy, chromatography, electrophoresis, and ESR spectroscopy as well as high-intensity gamma-ray sources, pulsed- and continuous-beam electron accelerators, and various organic-chemical analytical equipment are available.

Contact: Michael G. Simic, C206 Radiation Physics Bldg., 301/975-5558.

Neutron Fluence Measurement and Neutron Physics

NBS researchers are studying industrial applications of neutron fluence and dose determination in the neutron energy region from thermal to 20 MeV. They are concentrating on the development of effective methods to transfer personnel protection technology to the private sector. This research provides a basis for standardizing personnel protection control procedures in nuclear reactor and high-energy accelerator operations, for example.

Specific research projects involve: measurement of reference standard neutron reaction cross sections; characterization of reference fission deposits; development of neutron detectors with fast timing; calibrations using standard neutron and gamma-ray fields; and applications of neutron resonance radiography.

Equipment available includes a 100-MeV linac-based dedicated pulsed neutron source, a 3-MV pulsed positive-ion accelerator, and a 20-MW nuclear reactor.

Contact: Oren A. Wasson, B111 Radiation Physics Bldg., 301/975-5567.

Ultraviolet and Soft X-Ray Radiation Effects

To produce radiation for experimental purposes, NBS has built a synchrotron ultraviolet radiation facility (SURF-II). SURF-II is a 300-MeV electron storage ring that radiates high-intensity synchrotron radiation in the energy range from about 3 nm (400 eV) in the soft x-ray region to wavelengths in the visible region of the spectrum. The radiation is highly collimated, nearly linearly polarized, and of calculable intensity. Six beam lines are available and a user's program is in operation. SURF-II is well suited for several different types of research, such as atomic, molecular, biomolecular, and solid-state physics; surface and materials science; radiation chemistry and radiation effects on matter; ultraviolet and x-ray optical systems; and the calibration, characterization, and development of spectrometers and detectors.

NBS scientists are particularly interested in conducting collaborative research in: the use of soft x-ray synchrotron radiation for high-resolution lithography; measurement of the reflection characteristics of novel, high-efficiency, multilayer far ultraviolet optical devices; and calibration, characterization, and development of spectrometers and detectors.

Other available equipment includes a state-of-the-art multipurpose detector calibration facility, a large ultrahigh vacuum spectrometer calibration chamber, and a beamline dedicated to high-resolution radiation research with a 6.65-m vacuum spectrometer with a resolving power of about 300,000.

Contact: Robert D. Madden, A249 Physics Bldg., 301/975-3726 or William R. Ott, B206 Metrology Bldg., 301/975-3709.

Optical Pyrometry, Radiometry, Photometry

The U.S. defense, aerospace, health, lighting, and photographic industries require radiometric measurements for product development, quality control, and equity in trade. Compatibility of industrial radiometric standards with national and international standards is a key requirement to ensure a competitive position in world markets for these industries. To help ensure reliable radiometric measurements, NBS is conducting radiometric research in the near-ultraviolet, visible, and infrared spectral regions and developing accurate standards and calibration procedures for these regions.

Specific research focuses on calibration of near-infrared pyrometers; geometrically total spectral flux standards; detector-based radiometric standards; diode-array radiometry, photometry, and colorimetry; low-light-level calibration standards; near-infrared detectors; infrared spectral radiance standards; and absolute spectral analyzer systems. Available for these projects is sophisticated optical equipment such as tunable dye lasers, electro-optical devices, and interferometers.

Contact: A. Russell Schaefer, A313 Metrology Bldg., 301/975-2331.

Radiation Processing

To enhance quality control methods employed in industrial radiation processing of foods and the production and use of medical devices, electronic components, and polymers, NBS researchers are developing standardization and measurement assurance methods related to industrial high-dose applications of ionizing radiation. As part of this program, Bureau scientists are investigating radiation chemical mechanisms and kinetic studies applied to chemical dosimetry systems in the condensed phase, including liquids, gels, thin films, and solid-state detectors. They plan to examine such sensor materials as doped plastics, solid-state matrices, organic dye solutions, semiconductors, scintillators, biopolymers, amino acids, metalloporphyrins, and organic or inorganic aqueous solutions and gels.

In this research, scientists use a number of analytical methods including transmission and fluorescence spectrophotometry, electron spin resonance spectrometry, chemiluminescence photometry, as well as fiber optics analysis, microcalorimetry, pulse radiolysis, and conductivity measurements. Various x-ray and gamma-ray sources and electron accelerators with energies in the 0.1- to 10-MeV range are employed. In addition, conventional ultraviolet, visible, and infrared spectrophotometers and spectrofluorimeters, high-intensity gamma-ray sources, pulsed and continuous beam electron accelerators, and various organic-chemical analytical equipment are available.

Contact: William L. McLaughlin, C209 Radiation Physics Bldg., 301/975-5559.

Vacuum Ultraviolet Radiometry

As part of its research to understand and measure various forms of radiation, NBS is conducting vacuum ultraviolet studies involving radiation damage, polymerization of organic molecules, and solar simulation. NBS scientists have worked with industry researchers to develop and test vacuum ultraviolet instrumentation, new spectrometer designs, and detector systems, especially for flight in space.

By combining an ultrahigh vacuum, high-resolution scanning electron microscope with a new, compact electron spin-polarization detector, physicists (l. to r.) Gary Hembree, Robert Celotta, John Unguris, and Daniel Pierce can observe simultaneously the magnetic character of a surface and its physical structure over dimensions as small as 100 angstroms.

They have also collaborated on special sources, narrow band filters, and lasers.

Bureau scientists are interested in doing cooperative research in several other areas including studying the platinum-neon hollow cathode lamp as a secondary standard, laser plasmas as secondary standards, and a spark discharge light source as a secondary standard. State-of-the-art radiometric facilities and advanced optical equipment are available at the Bureau for these studies.

Contact: J. Mervin Bridges, 301/975-3228 or Jules Z. Klose, 301/975-3230, B66 Physics Bldg.

Submicron Physics

Well-characterized, focused electron beams are used to interrogate the properties of surfaces and magnetic materials on a microscopic scale. NBS conducts a broad-based research program exploring the physics of submicron systems with electron microprobes. The program includes studies of electron-surface interactions, surface magnetism, electron interaction theory, and electron spin polarization phenomena. Extensive experimental facilities are available for this research, including sources and detectors of spin polarized electrons, a scanning electron microscope equipped for secondary electron spin polarization analysis, and a scanning tunneling microscope.

Scanning electron microscopy with polarization analysis (SEMPA) is a unique measurement capability developed by NBS scientists to allow the high-resolution (~10 nm) imaging of magnetic microstructure independently of surface topography. With this technique, they are studying fundamental magnetic phenomena, the properties of high-density magnetic recording media, and small-particle magnetism. Bureau researchers are using the scanning tunneling microscope (STM) to study surface topography at the atomic level, mechanisms of film growth at the submonolayer level, reconstructions of semiconductor surfaces, and, ultimately, correlation of surface microstructure with macroscopic properties.

Contact: Robert J. Celotta, B210 Metrology Bldg., 301/975-3710.

Standard Reference Data

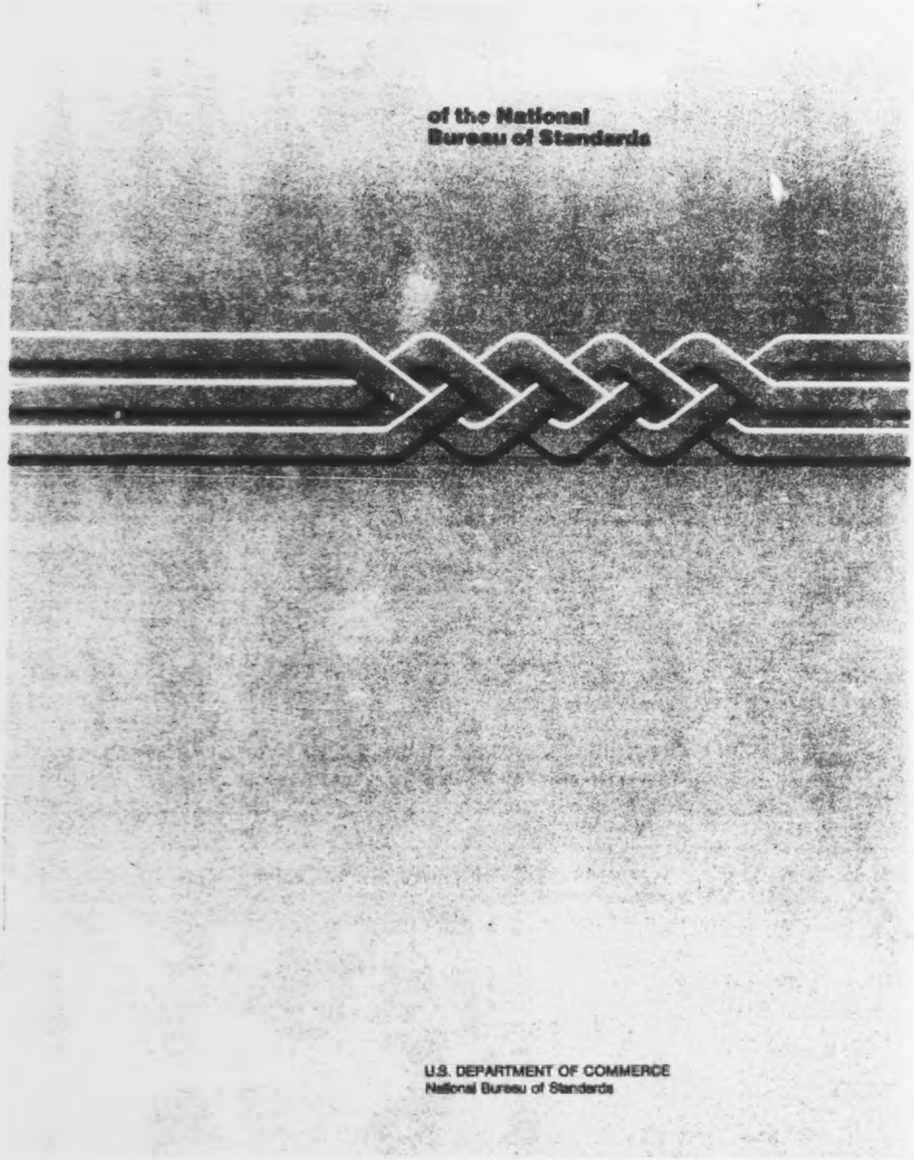
Computerization of Standard Reference Data

Using computers to provide timely and inexpensive access to reliable chemical, physical, and materials data contributes greatly to increased productivity and lower manufacturing costs of industrial operations. The NBS Standard Reference Data program works closely with industry to develop the tools and standards necessary for computerizing industrial technical data – the numbers, graphics, tables, and text that convey research results.

The National Standard Reference Data System, coordinated by NBS, is a major focal point in the United States for the evaluation of chemical, physical, and materials properties data. The NBS Standard Reference Data program has made a commitment to provide national leadership in the computerization of these evaluated data, including database design, data interchange standards, and data dissemination.

NBS research combines expertise in the physical sciences with specialized knowledge in computer science. Areas of activity include preparation of databases of evaluated data and predictive software for use on personal computers, conversion and combination of published data compilations into searchable databases, standardization of formats for scientific information, development of expert systems, and establishment of distributed systems linking scientific databases. Computer and telecommunications capabilities at NBS offer challenging alternatives to the handling of these projects, with state-of-the-art mainframes, minis and micros, database management systems, graphics, and applications software available.

Contact: David R. Lide, A323 Physics Bldg., 301/975-2200.



of the National
Bureau of Standards

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

NBS Gaithersburg Laboratories

NBS Boulder Laboratories

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Foreword

Every laboratory in this country is a valuable national resource. Along with the people who work in these facilities, U.S. laboratories constitute the basic foundation of this country's scientific and industrial strength.

As the nation's foremost science and engineering measurement laboratory, the National Bureau of Standards has some of the premier research and testing facilities in the United States, and several of our laboratories are unequaled anywhere in the world. Bureau scientists and engineers use these special facilities to pursue the measurement-related work that U.S. science and industry need to grow and prosper.

Many of the facilities are available for use by the scientific and engineering communities either on a cooperative or independent basis. NBS has a long history of cooperative work in these laboratories with researchers from industry, government, and academia. For example, our Research Associate Program, established in the 1920's, has provided the opportunity for numerous collaborative projects over the years. Through this program, research associates have their salaries paid by the sponsoring organizations while NBS contributes its expertise and permits researchers to use the Bureau's facilities and equipment.

Now, recognizing the strong challenges from abroad and the need for U.S. researchers to pool their resources, we have decided to make selected NBS facilities available to U.S. researchers for proprietary work on a cost-recovery basis, when equal or superior facilities are not otherwise readily available. We hope this new policy will increase the transfer of technology to industry and encourage commercially important research that otherwise might not be done.

This brochure highlights only a small number of the special facilities available at NBS and provides information about their availability for collaborative or independent research and testing. Individuals or organizations wishing to use a facility should contact the facility manager listed in each write-up. NBS has designed its system for reviewing such requests to be as efficient and responsive as possible, to encourage maximum use and minimal paperwork on the part of both NBS and the prospective user.

We encourage you to take advantage of the nation's investment in NBS.

E. Ambler.

Ernest Ambler
Director

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NBS Research Reactor

The National Bureau of Standards research reactor is a national center for the application of reactor radiation to a variety of problems of national concern. Major program areas at the reactor include the application of neutron scattering methods to research in materials science, trace analysis by neutron activation, nondestructive evaluation (via neutron radiography and scattering), neutron standards and dosimetry, and isotope production and radiation effects.

Capabilities:

The NBS reactor is an enriched uranium, heavy-water moderated reactor operating at 20 MW and producing a peak thermal core flux of 4×10^{14} neutrons/$cm^2 \cdot s$. A large cold neutron source is under development which will increase the flux of long wavelength (> 1 nm) neutrons by an order of magnitude.

Experimental facilities are available for neutron single-crystal and powder diffraction and inelastic scattering studies, small-angle neutron scattering (SANS), sample preparation, irradiation and post-irradiation processing, neutron depth profiling, neutron dosimetry, and related physics.

Applications:

Elastic Scattering—Atomic-scale phase structure in catalysts, electronic and dielectric ceramics, semiconductors, and biomaterials, for example. Submicron structure studies including molecular conformations in block copolymers, characterization of microcracks and porosity damage in ceramics, creep cavitation in metal alloys, and characterization of precipitate distributions in high-strength, low-alloy steels. Phase transition kinetic studies in alloys. Atomic-level magnetic structure and behavior in crystalline and amorphous materials.

Inelastic Scattering—Lattice dynamics and vibrational spectroscopy studies of hydrogen in metals at low concentrations, vibrational spectra of molecules adsorbed in heterogeneous catalysts, diffusion processes for small molecules in solids, magnetic properties.

Element Analysis—Neutron activation analysis method development; applications to studies in environmental chemistry, nutrition, biomedicine, and energy systems. Neutron capture prompt gamma activation analysis method development.

Availability:

There are 25 experimental facilities at the reactor providing roughly 125,000 instrument hours per year to approximately 200 users. The users of the facilities represent 18 NBS divisions and offices, 18 other federal agencies, and approximately 35 university and industrial laboratories. Collaborative programs are arranged through the NBS Reactor Radiation Division or other NBS groups using the facility. Proposals for collaborative or independent use of the facility are reviewed by a committee which examines the merit and conditions of each application.

Contact:

Dr. Robert S. Carter, Reactor
Radiation Division, Room A106
Reactor Building, National
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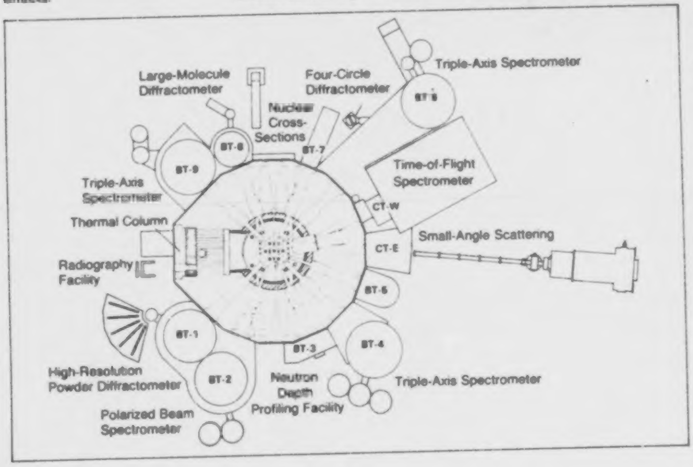
Gaithersburg, MD 20899.
Telephone: 301/921-2421.


Large-Molecule Diffractometer
Four-Circle Diffractometer
Triple-Axis Spectrometer
Nuclear Cross-Sections
BT-8
BT-7
BT-6
BT-9
Triple-Axis Spectrometer
Time-of-Flight Spectrometer
CT-W
Thermal Column
Small-Angle Scattering
CT-E
Radiography Facility
BT-5
BT-1
BT-3
BT-4
High-Resolution Powder Diffractometer
BT-2
Neutron Depth Profiling Facility
Triple-Axis Spectrometer
Polarized Beam Spectrometer

Experimental Facilities and Research Areas at the NBS Reactor

Neutron Depth Profiling Facility

Neutron Depth Profiling Facility

The neutron depth profiling (NDP) facility at the National Bureau of Standards uses a neutron beam for nondestructive evaluation of elemental depth distributions in materials. Working with the Bureau's 20 MW nuclear reactor, researchers use the technique to provide concentration profiles for characterizing the near-surface regime of semiconductors, metals, metallic glasses, and other glasses to depths of several micrometers. The facility uses filters and collimators to create a high-quality neutron beam with good thermal neutron intensity and minimum contamination with fast neutrons and gamma rays. An aluminum target chamber is used to contain the samples in a vacuum, and a full array of electronic components is available for data acquisition and analysis.

Capabilities:

With the clean thermal neutron beam created by the reactor, depth profiling can be carried out with sensitivities approaching 10^{13} atoms/cm^2. The method is not destructive to the sample and produces negligible radioactivation and energy deposition in the sample. A single analysis produces a profile typically 5 to 20 μm deep with a resolution of ~30 nm, which is limited at present by the energy resolution of the surface barrier detector used. Once calibrated with the appropriate elemental standard, the concentration scale is fixed independently of the sample composition. The depth scale is monotonically related to the energy scale by means of the charged particle stopping power. Elements that do not produce charged particles under thermal neutron irradiation contribute no interference.

Applications:

Some of the many applications of NDP include range measurements for boron implanted in silicon; observations on near-surface boron in glass; boron concentration profiles in thin layers of borophosphosilicate glass; measurement of helium release in single-crystal nickel to investigate the He-trapping phenomena; and measurement of high-dose nitrogen implants in steels.

Availability:

The facility is available to qualified researchers on an independent or collaborative basis with NBS staff.

Contact:

Dr. Ronald F. Fleming, Inorganic Analytical Research Division, Room B108 Reactor Building, National Bureau of Standards, Gaithersburg, MD 20899. Telephone: 301/921-2166.

High-Resolution Neutron Powder Diffractometer

The high-resolution neutron powder diffractometer at the National Bureau of Standards research reactor, with five detectors for simultaneous collection of data from different parts of the diffraction pattern, is used widely for studies of the structures of many important crystalline materials that are not available as large single crystals. Accurate structural information can be obtained at temperatures from 4 to 1200 K, which is often the key to understanding the properties of technologically important materials, including catalysts, magnetic materials, high-temperature alloys, minerals and ceramics, and ionic conductors.

Capabilities:

The NBS powder diffractometer system is designed to be "user-friendly" and highly flexible. For example, a variety of programs are available and documented, which allow the use of constrained refinement procedures to make use of known structural information on atomic or molecular units of the material being examined, along with advanced procedures for background, lineshape, and absorption corrections. Structural information can be analyzed at the NBS reactor using a high-speed, high-capacity superminicomputer or can be provided in convenient form on a floppy disk to be analyzed back at the user's own laboratory. A sophisticated technicolor graphics system is also available, with appropriate software to allow two- or three-dimensional displays of materials crystal structures, including stereographic projections.

Availability:

This facility is available for use by industry, academia, and government on either a collaborative or independent basis under the supervision of the NBS Reactor Radiation Division staff. The NBS powder diffractometer system is heavily utilized. Projects are scheduled on a regular basis by a committee of NBS staff.

Contact:

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Radiation Division, Room A106
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Bureau of Standards,
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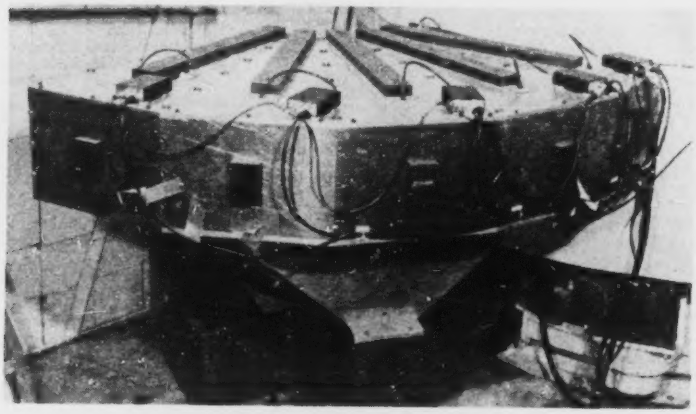
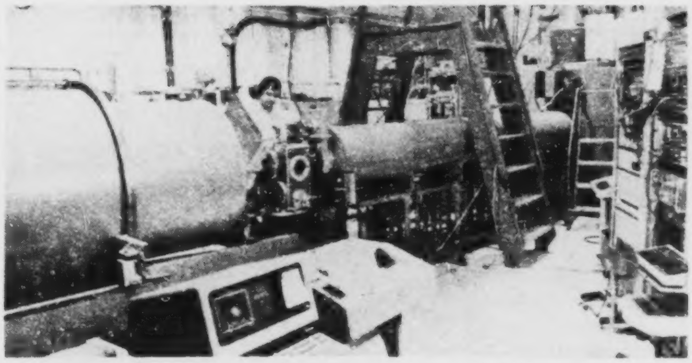
Telephone: 301/921-3634.

High-Resolution Neutron Powder Diffractometer



Small-Angle Neutron Scattering Facility



Small-Angle Neutron Scattering Facility

Small-angle neutron scattering (SANS) is a technique in which a highly collimated beam of low-energy (long wavelength) neutrons is used to probe the structure of materials on a size scale from roughly 1 to 100 nm. The small-angle diffraction patterns produced by structural features in this size regime—for example, by small precipitates or cavities in metal alloys, by micropores or cracks in ceramics, or by polymers or biological macromolecules—can be analyzed to yield important information about the size and shape of the scattering centers as well as their size distribution, surface area, and number density. In contrast to a complementary technique such as electron microscopy, a relatively large volume (up to about 1 cc) of material is examined in a SANS measurement. As a result, the information obtained represents statistical averages which are characteristic of the bulk material and which are related to bulk properties.

Capabilities:

The SANS spectrometer at the National Bureau of Standards reactor utilizes a variable speed velocity selector to provide a beam whose wavelength is continuously tunable from 0.5 to 1.2 nm. Several choices of pinhole beam collimation are available, including a unique converging beam system which provides the instrument's best angular resolution (1.6 milliradians). Apparatus is available for maintaining samples at temperatures from 4 to 700 K and in magnetic fields up to 15 kilogauss.

For measurements at near ambient temperatures (0 to 80 °C), a multispecimen sample stage is used to change samples automatically under computer control. The neutron detector is a large (65 by 65 cm^2), two-dimensional, position-sensitive proportional counter which, in most cases, enables an entire scattering pattern to be recorded in a single measurement. The detector can, however, be rotated about the sample position to measure scattering at larger angles when necessary. An interactive color graphics terminal is used for imaging and analyzing completed data sets. Computer software is available for many forms of routine data analysis and model fitting.

Applications:

SANS is becoming an increasingly important tool in materials science and is used, for example, to study the kinetics and morphology of precipitate growth in high-strength alloys, to measure molecular conformation of polymers and biological macromolecular complexes, to detect and quantify early stage creep and fatigue damage in metals and ceramics, and to study the magnetic microstructure of new crystalline and amorphous magnetic materials. In many of these applications, especially those involving polymers, biology, and magnetism, the structural information provided by SANS cannot be obtained by any other technique.

Availability:

The SANS facility is heavily utilized by NBS staff and others in industry, universities, and government. Proposals for collaborative or independent use of the facility are reviewed by a SANS scheduling committee, which examines the merit and conditions of each application.

Contact:

Dr. Charles J. Glinka, Reactor
Radiation Division, Room B106
Reactor Building, National
Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3634.

[redacted]

140 MeV Electron Linear Accelerator

The National Bureau of Standards operates an electron linear accelerator (LINAC) which can produce beams in excess of 50 kW and be used with high-quality beam control. This facility provides the capability for conducting precision research with high-energy beams of electrons, photons, and neutrons and for developing measurement standards for these types of radiation. This nine-section, L-Band, traveling-wave LINAC and its beam transport system provide a wide variety of beam conditions to satisfy user needs. The electron beam can be directed to either of two heavily-shielded underground target rooms or to an above-ground target room where secondary neutron beams are produced for time-of-flight measurements at distances up to 200 m.

Capabilities:

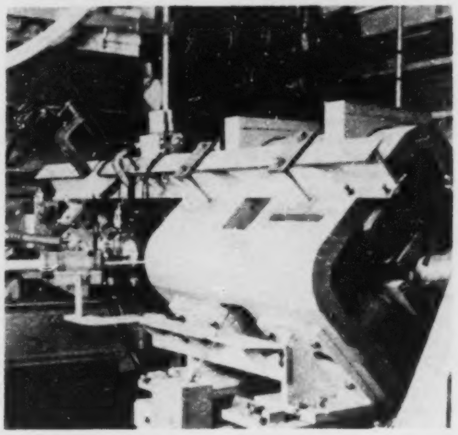
The LINAC operates at energies between 14 and 140 MeV, peak current up to several amperes, and average current up to 200 μA. Beam pulse length is variable from 5 ns to 5 μs, at pulse repetition rates up to 720/s. The time-of-flight facility includes flight paths of 5, 20, 60, and 200 m. Neutron production targets provide 10^{13} n/sec (4π) at energy ranges of thermal to 1 KeV, 1 KeV to 5 MeV, and 100 KeV to 15 MeV. Automated data processing equipment is available for rapid collection and analysis of data from state-of-the-art one- and two-dimensional neutron detectors. A high-resolution electron spectrometer and a photonuclear activation irradiation station are available in the target rooms.

Applications:

The LINAC is used in a broad range of programs in physical research and standards development. Examples of the wide variety of experimentation performed include: activation analysis with photon-induced reactions, preparation of Mossbauer sources, preparation of neutron-deficient radioactive isotopes, neutron cross-section measurement by time-of-flight including both total and reaction cross sections, and resonance neutron radiography.

Also, research is conducted in electron-volt neutron scattering, nuclear structure studies by means of photonuclear reactions and electron scattering, studies of the measurement of high-power electron beams with non-intercepting beam monitors, absolute methods of high-power electron-beam current measurement, accelerator research, and medical dosimetry for high-energy radiation therapy.

These facilities are used to produce neutron data and standards for neutron personnel dosimetry, for applied nuclear technology, and for producing neutron radiography measurement methods and standards used to measure concentrations of specific elemental isotopes in various materials found in reactor construction materials and to test welds for the presence of elements not detectable by x rays. Two-dimensional detectors and rotating target techniques have been developed and used with these facilities to provide the capability of three-dimensional analysis (i.e., neutron tomography).



Measuring Room at the Linear Accelerator

Availability:

The LINAC and associated experimental areas are available without charge for collaborative research by NBS and outside scientists in areas of mutual interest and benefit. In special cases, independent research of benefit primarily to an outside user can be performed with this facility on a time-available, cost-recovery basis. Current plans call for the LINAC and its associated research facilities to be available in the present configuration until July 1986. At that time the LINAC will be shut down for modification and dedication strictly to neutron research and standards development. Electron and photon research and standards work will be transferred to the new 185 MeV continuous-wave, microtron-type electron accelerator. The modified LINAC and the microtron should be available for research and standards development in early or mid-1987.

Contact:

Dr. Sam Penner, Radiation Source and Instrumentation Division, Room B102 Radiation Physics Building, National Bureau of Standards, Gaithersburg, MD 20899.
Telephone: 301/921-2503.

[redacted]

Synchrotron Ultraviolet Radiation Facility-II

The Synchrotron Ultraviolet Radiation Facility-II (SURF-II) is a 280 MeV electron storage ring at the National Bureau of Standards that radiates synchrotron radiation which is highly collimated, nearly linearly polarized, and of calculable intensity. Six beam lines are available, and a user's program is in operation. SURF-II is well-suited for studies in: atomic, molecular, biomolecular, and solid state physics; surface and materials science; electro-optics; and chemistry and radiation effects on matter.

Capabilities:

The typical storage ring electron beam current is 50 mA at 280 MeV. The photon intensity in the region 60 to 120 nm is about 11×10^{11} photons per second per milliradian of orbit for an instrumental resolution of 0.1 nm. Experiments can be made conveniently throughout the wavelength range 4 to 1000 nm, from the soft x-ray region to the infrared. A grazing incidence and several toroidal grating monochromators are available to disperse the radiation. A large, ultra-high vacuum spectrometer calibration chamber, 1.2 m by 1.2 m by 2.5 m, is available for radiometric applications. A 6.65-m, normal-incidence vacuum spectrometer, with resolving power of about 300,000, is available on a beam line dedicated to high-resolution vacuum ultraviolet radiation research.

Applications:

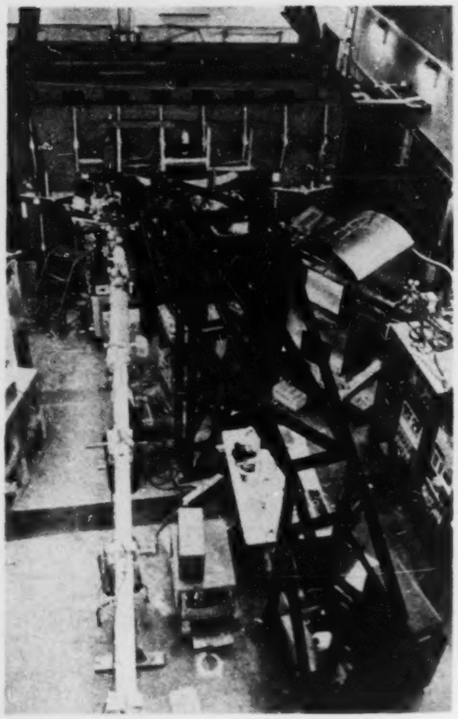
The continuous radiation from SURF-II is used as a national standard of spectral irradiance for radiometric applications and for fundamental research in: 1) atomic and molecular absorption spectroscopy; 2) optical properties of materials; 3) electron density of states in solids; 4) surface characterization; 5) photoelectron spectroscopy; 6) molecular kinetics and excitation and ionization dynamics; and 7) radiation interactions with matter (e.g., lithography, radiation damage, dosimetry, photobiology).

Availability:

Beam time on SURF-II is available to any qualified scientist provided beam line vacuum requirements are met and scheduling arrangements can be made Proposals should be submitted for NBS review at least 2 months before use of the facility is desired. Informal contact is also encouraged.

Contact:

Dr. Robert P. Madden, Radiation Physics Division, Room A251 Physics Building, National Bureau of Standards, Gaithersburg, MD 20899. Telephone: 301/921-2031.



Synchrotrun Ultraviolet Radiation Facility-II

Metals Processing Laboratory

The metals processing laboratory at the National Bureau of Standards contains special facilities for the production of rapidly solidified alloys, including equipment for inert gas atomization and electrohydrodynamic atomization to produce rapidly solidified alloy powders, melt-spinning to produce rapidly solidified alloy ribbons, and electron beam and laser surface melting to produce rapidly solidified surface layers. Hot isostatic pressing equipment is available for consolidation of the alloy powders. A plasma-transferred arc system is used to study alloy coating processes.

Capabilities:

Inert Gas Atomization—The inert gas atomization system can be used to produce up to 25 kg of rapidly solidified alloy powder per batch while maintaining an inert environment throughout the atomizing and powder handling process. High-pressure inert gas (Ar, He, or Ar-He mixtures) impinging on a liquid metal stream breaks up the liquid into small droplets which rapidly solidify. Cooling rates are up to 10^5 K/s. The atomized powder, entrained in the inert gas flow, is collected in removable, vacuum-tight canisters.

Electrohydrodynamic Atomization—In the electrohydrodynamic atomization system, a liquid metal stream is injected into a strong electric field. The field causes the stream to disintegrate into droplets which rapidly solidify to produce extremely fine (<1 μm diameter) alloy powder. Powder produced by this process is well-suited for studying solidification dynamics. As the system is presently configured, small quantities for microscopic examination can be produced from alloys with melting points up to 900 °C.

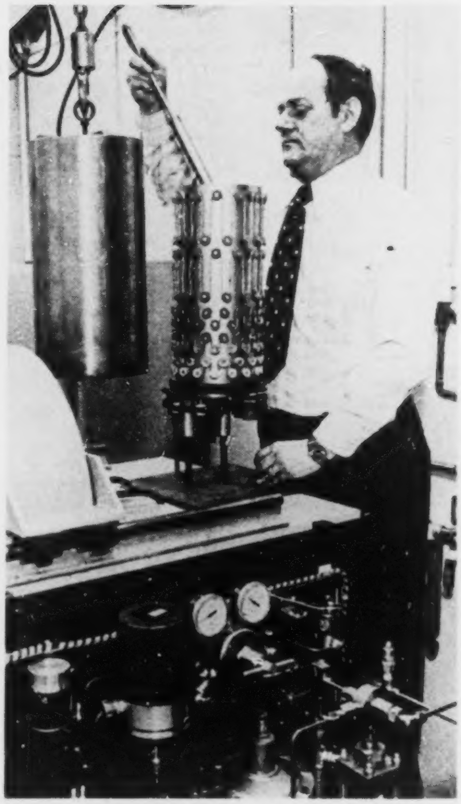
Melt Spinning—Melt spinning techniques can be used to produce rapidly solidified alloys in ribbon form. Because of the high cooling rates (up to 10^6 K/s) with this method, amorphous alloys as well as crystalline alloys can be produced. Ribbons up to 3 mm wide and up to 0.05 mm thick can be produced in quantities of several grams per batch. Materials with a wide range of melting points, from aluminum alloys to superalloys, have been produced.

Electron-Beam and Laser Surface Melting—An electron-beam system which provides

Electrohydrodynamic Atomization Chamber in the Metals Processing Laboratory surface melting and subsequent rapid resolidification of surface layers can be operated in either a pulsed or continuous mode. The electron beam can be focused to a spot less than 1 mm in diameter and deflected at frequencies up to 5 kHz. A pulsed neodymium-glass laser complements the electron-beam unit in producing these surface-modified layers. The laser produces pulses with energies up to 200 J with pulse width variable from 0.1 to 7 ms.

Hot Isostatic Press—A hot isostatic press (HIP) with microprocessor control of the temperature-pressure-time cycle is available for consolidation of powder or compacted powder shapes. The HIP has a cylindrical working volume 15 cm in diameter and 30 cm high. The maximum working pressure is 207 MPa. The molybdenum furnace has a maximum heating rate of 35 K/min and is capable of maintaining 1500 °C.

Plasma-Transferred Arc Coating System—The plasma-transferred arc equipment is capable of feeding independently one or two different types of powder deposits and automatically coating a surface area up to 2 in wide by 5 ft long in a single pass. This system is also capable of providing deposits under conditions of constant deposition power, while the relative heating of the substrate and deposit may be independently controlled.



Hot Isostatic Press in the Metals Processing Laboratory

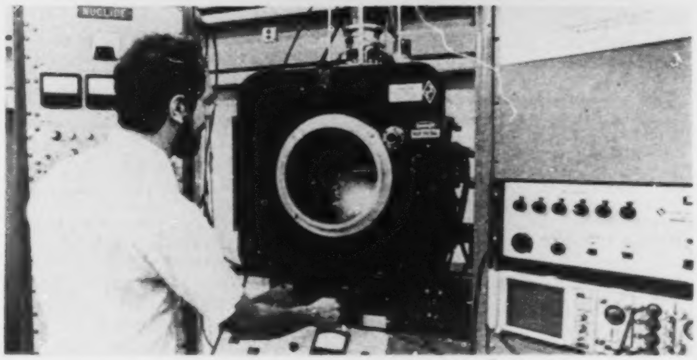
Availability:

These facilities are designed to produce alloy research samples which are difficult otherwise for users to obtain. Typically, industrial companies or universities send workers to NBS to participate in preparing alloys of special industrial and scientific interest for further analyses in their home laboratories and to collaborate with NBS scientists in investigations of generic relationships between processing conditions and resulting alloy microstructures and properties.

Contact:

Dr. John R. Manning, Metallurgy Division, Room A153 Materials Building, National Bureau of Standards, Gaithersburg, MD 20899.
Telephone: 301/921-3354.

Melt Spinning Apparatus in the Metals Processing Laboratory



Electron-Beam Surface Melting Apparatus in the Metals Processing Laboratory

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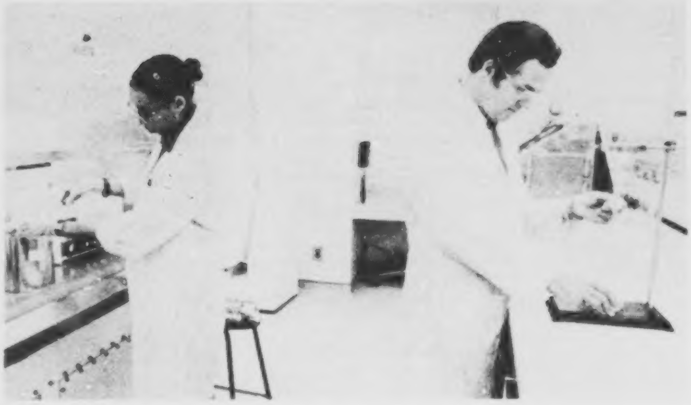
Toxic Chemicals Handling Laboratory



Toxic Chemicals Handling Laboratory

The toxic chemicals handling laboratory at the National Bureau of Standards is used to store, handle, and analyze organic compounds that are extremely toxic and/or possess undesirable biological activity.

The laboratory was designed through the joint efforts of scientists from the NBS Center for Analytical Chemistry and a private architectural and engineering firm. Its features offer special protection for those using the laboratory. The facility was specially designed and is used to allow scientists to perform research that involves the characterization or analysis of toxic or mutagenic organic materials in a safe manner. The laboratory is equipped with facilities for weighing, sample storage, sample preparation (extractions, etc.), and gas and liquid chromatographic analyses.

Capabilities:

Laboratory Work Space—The laboratory has approximately 10 m of bench space for sample preparation and analytical activities. The air throughout the working area in the laboratory is recirculated at a rate of 225 m^3/min (~8000 ft^3/min) through charcoal filters to remove organic fumes and HEPA filters to remove particulate material. The air flow is directed so that scientists using the facility are continuously bathed with clean air. The air supply to the laboratory is ~11 m^3/min less than the exhaust, thereby preventing diffusion of possibly toxic vapors from the facility into the hall and adjacent laboratories.

Cabinet Space—The laboratory has 5 m^2 of actively vented cabinet space for storage of toxic chemicals. Air flowing from the storage areas is charcoal filtered and totally exhausted to the outside.

Safety Hoods—The laboratory is equipped with two air barrier fume hoods for manipulations of pure chemicals (including weighing) or concentrated solutions. All air entering the hoods is exhausted to the outside after charcoal filtration.

Other—The laboratory also has shower facilities.

Availability:

The laboratory and its facilities can be shared with qualified staff from NBS, other government agencies, universities, and industry. Since space is limited, preference will be given to NBS users and to projects that are related to NBS interests. Due to the toxic nature of the chemicals involved in various experiments and stored in the facility, all projects will be monitored by NBS personnel.

Contact:

Dr. Willie E. May, Organic Analytical Research Division, Room A113 Chemistry Building, National Bureau of Standards, Gaithersburg, MD 20899. Telephone: 301/921-3778.

[redacted]

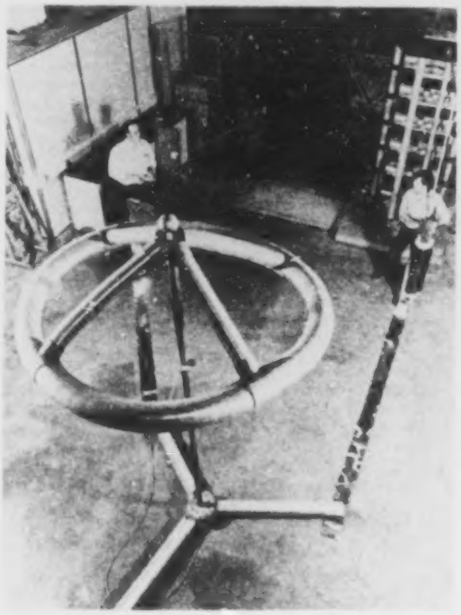
High-Voltage Measurement Facility

The National Bureau of Standards maintains a high-voltage measurement facility in which it develops and evaluates the measurement techniques needed in the orderly delivery of electric power for defense and to support industrial and university research. The major programs now being pursued using this facility are the measurement of transient voltages and currents, the development of techniques to quantify prebreakdown and breakdown phenomena in liquid and gaseous dielectrics, and the measurement of low-frequency electric and magnetic fields.

Capabilities:

With existing power sources, direct voltages of 300 kV, 60 Hz alternating voltages of 175 kV, and standard lightning impulses of 500 kV can be produced. Selected waveforms, such as microsecond duration trapezoidal waveforms up to 300 kV and gated 60 Hz waveforms up to 100 kV, are also available. Supporting equipment includes high-voltage standard capacitors rated at 200 kV; high-accuracy, current-comparator bridges for 60 Hz measurements; a precision dc divider rated at 200 kV; dividers to measure standard lightning impulses up to 1 MV peak; partial discharge measurement systems; high-speed cameras and supporting optical equipment; a computer-controlled system to measure the electric field in transformer oil; a mass-chromatograph/mass-spectrometer system; a low-speed wind tunnel; and a system to produce a known electric field and current density in air at atmospheric pressure.

The experimental capability is presently being expanded. For example, a 400 kA source of pulsed currents on millisecond to second time scales is scheduled for installation during 1984. A calibration system for instruments used to measure transient voltages and currents on nanosecond time scales also is being developed.



Applications:

Instrumentation and Component Evaluation—Impulse, ac, and dc dividers; electric and magnetic field meters; capacitors; transformers; lightning arresters; and ion counters.

Dielectrics Research and Development—Chemical degradation studies; measurement of the fundamental processes of discharge initiation; onset and magnitude of partial discharges; space charge measurement; streamer propagation studies.

Availability:

The high-voltage facility is used by staff from the NBS Electrosystems Division and by guest workers from industry, universities, and other federal agencies. Use of the facilities must be scheduled in advance. Because of the complexity of the system, it is anticipated that typical use of the facility will be in the form of a collaborative investigation with staff from the Electrosystems Division.

Contact:

Dr. Robert E. Hebner, Electrosystems Division, Room B344
Metrology Building, National
Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3121.

High-Voltage Measurement Facility

Transverse Electromagnetic (TEM) Cells

The National Bureau of Standards has designed and constructed several transverse electromagnetic (TEM) cells that are available for use. A TEM cell is a device for performing radiated electromagnetic emission and susceptibility measurements of electronic equipment. It is designed based on the concept of an expanded transmission line operated in a TEM mode. The cell is a two-conductor system with the region between the inner and outer conductors used as the test zone. The tapered sections at both ends are required to match the cell to standard 50 Ω coaxial-cable connectors.

Capabilities:

The cell provides a shielded environment for testing without introducing multiple reflections experienced with the conventional shielded enclosure. It simulates very closely a planar far field in free space and has constant amplitude and linear phase characteristics. The external electromagnetic signals will not affect the measurement of low-level radiated emission from the device under test. The high-level test field generated inside a cell for radiated susceptibility tests will not interfere with external electronic systems.

Applications:

In addition to radiated electromagnetic compatibility/interference (EMC/EMI) testing, other applications of the TEM cells include the calibration of antennas and the study of biological effects of radio-frequency radiation.

Limitations:

The usable frequency range is limited by an upper bound determined by the appearance of the lowest high-order mode. The volume available for testing purposes is inversely proportional to this upper frequency limit. The size of the device to be placed inside a TEM cell for testing should be small relative to the available test volume in order that the field structure associated with the ideal TEM mode existing in an empty cell not be significantly perturbed.

Availability:

Several TEM cells with five different sizes and five upper frequency limits in the range 100 MHz to 1 GHz are available. In collaborative programs, NBS staff are available to advise and interpret measurement results. Independent testing also can be arranged through the Electromagnetic Fields Division.

Contact:

Dr. Mark T. Ma, Electromagnetic Fields Division, Room 4073 Radio Building, National Bureau of Standards, Boulder, CO 80303.
Telephone: 303/497-3800.

Electromagnetic Anechoic Chamber

The electromagnetic (EM) anechoic chamber at the National Bureau of Standards is a facility for generating standard (known) electromagnetic fields. Such fields are fundamental to the research, development, and evaluation of antennas, field probes, and EM material properties.

Capabilities:

EM fields up to 100 V/m can be established in the chamber over the broad frequency range from 200 MHz to 18 GHz, and up to 200 V/m for certain frequency bands above 1 GHz. A majority of the individual systems which comprise the measurement system are under computer control, thus enhancing statistical control of the measurements. Work is underway to extend the frequency range to 40 GHz and to improve the computer control of the chamber systems. The chamber dimensions are 8.5 m, 6.7 m, and 4.9 m in length, width, and height, respectively.

Applications:

☐ Research, development, and evaluation of new EM field generation and measurement methods
☐ Antenna and field probe development and evaluation
☐ Calibration of field measurement instruments
☐ Susceptibility testing of electronic equipment
☐ Shielding effectiveness and material parameter studies
☐ Special tests for government agencies, industry, and universities

Availability:

This facility is used heavily in performing calibrations for industry and other government agencies. The facilities are available for independent or collaborative work with NBS.

Contact:

Dr. Norris S. Nahman, Electromagnetic Fields Division, Room 4643 Radio Building, National Bureau of Standards, Boulder, CO 80303.
Telephone: 303/497-5167.

[redacted]

Ground Screen Antenna Range

The ground screen antenna range is an open area test site located at the National Bureau of Standards. The range is completely enclosed by an air-inflated, synthetic fabric structure which allows use of the facility on a year-round basis. The air-supported structure provides an unobstructed span of the entire range with no metal parts above the level of the ground plane.

Capabilities:

The ground screen consists of 1/4-in mesh galvanized hardware cloth stretched over a level concrete slab. The screen is 30.5 m wide by 61 m long and is spring-loaded around the perimeter to ensure uniform tension, a flat surface, and adequate compensation for thermal expansion. Antenna masts up to 9 m in height can be erected within the structure. The overall size of the ground screen permits far-field measurements in the HF portion of the spectrum while the mesh dimension provides for an efficient ground plane well into the UHF region.

Applications:

☐ Antenna calibrations
☐ Antenna patterns at any polarization
☐ Electromagnetic susceptibility measurements
☐ Electromagnetic radiated emission measurements
☐ Calibration of field intensity meters
☐ Wave propagation studies in frequency or time domains

Availability:

This facility is used heavily in performing calibrations for industry and other government agencies. The facilities are available for independent or collaborative work with NBS.

Contact:

Dr. Norris S. Nahman, Electromagnetic Fields Division, Room 4643 Radio Building, National Bureau of Standards, Boulder, CO 80303.
Telephone: 303/497-5167.

Ground Screen Antenna Range

[redacted]

Near-Field Scanning Facility for Antenna Measurements

Capabilities:

This automated facility is designed to measure the near-zone phase and amplitude distributions of the fields radiated from an antenna under test. Mathematical transformations are then employed to calculate the desired antenna characteristics. Near-field data can be obtained over planar, cylindrical, and spherical surfaces, with the planar technique being the most popular. Efficient computer programs are available for processing the large quantities of data required.

When operated in the planar mode, the facility is capable of measuring over a 4.5-m by 4.5-m area with probe position errors of less than ±0.01 cm. Improved position accuracy is possible with further alignment, especially over smaller areas. Antennas with apertures up to about 3 m in diameter can be measured with a single scan and the facility has been used successfully over the frequency range 750 MHz to 75 GHz. By early 1985 the facility will be enlarged so that larger antennas can be measured by scanning in segments.

Applications:

Antenna Characteristics—The facility is used primarily for determining the gain, pattern, and polarization of antennas. Accuracies are typically ±0.15 dB for absolute gain and ±0.10 dB/dB for polarization axial ratio. Patterns can be obtained down to the −50 to −60 dB levels with side lobe accuracy typically about ±1.0 dB at the −40 dB level. (The exact uncertainties depend on the frequency, type, and size of antenna, etc.) The near-field data can also be used to compute near-field interactions (e.g., mutual coupling) of antennas and radiated field distributions in the near zone.

Antenna Diagnostics—Near-field scanning is also a valuable tool for identifying problems and for achieving optimum performance of various types of antenna systems. It has, for example, been used to advantage in locating faulty elements in phased array antennas and for adjusting feed systems to obtain the proper illumination function at the main reflector. Phase contour plots of the near-field data can also be used to determine surface imperfections in reflectors used for antennas or compact ranges.

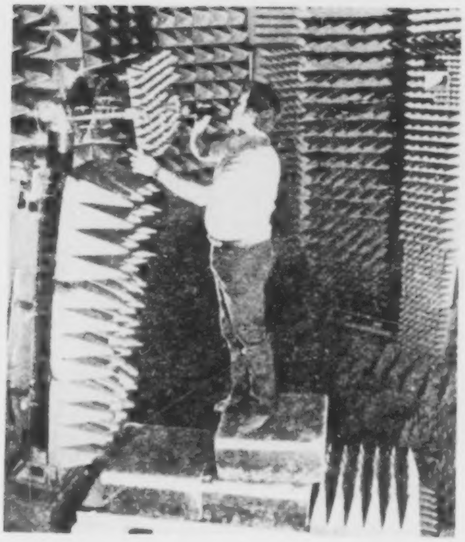
Probe Calibrations—The facility also is used as a far-field range for measuring the receiving characteristics of probes used to obtain near-field data. These measurements are required to determine the probe coefficients which, in turn, are used to calculate accurate probe-corrected far-field gain and pattern characteristics of an antenna.

Availability:

Two kinds of arrangements can be made to use this facility. The staff of the Electromagnetic Fields Division can perform specified tests or measurements on a reimbursable basis. In this case, the customer has no direct interaction with the facility; all measurements are performed by NBS staff and the customer is issued a test report. As an alternative, work may be performed on a cooperative basis with NBS staff. This arrangement permits the user the advantage of developing first-hand knowledge of the measurement processes, and the user is responsible in large part for the accuracy of test results. In either case, arrangements need to be made well in advance, and reimbursement is required for the facility use and time of NBS staff involved.

Contact:

Mr. Allen C. Newell, Electromagnetic Fields Division, Room 4065 Radio Building, National Bureau of Standards, Boulder, CO 80303.
Telephone: 303/497-3743.



Near-Field Scanning Facility

Outdoor Extrapolation Range for Antenna Measurements

Capabilities:

This unique facility was designed to perform accurate measurements of absolute gain and polarization of microwave antennas using the "Extrapolation Method" developed by the National Bureau of Standards in the early 1970's. It consists of two towers mounted on a pair of accurately aligned rails. The towers support all or parts of the source, receiver, and data systems as well as the rotators for supporting and positioning the antennas.

Both towers are free to move, and the separation distance between them can be varied smoothly from 0 to 60 m. The towers are approximately 6 m high and the antennas under evaluation can be mounted 1 to 2 m higher if necessary. Means are provided for accurately aligning the antennas and for maintaining that alignment for all separation distances. The rails were originally aligned using a transit and precision level so that the maximum angular deviation of the antennas was less than ±0.02 degrees about any axis as the towers were moved the full length of the rails.

Applications:

NBS uses this facility primarily for the accurate characterization of antennas by measuring absolute gain and polarization parameters. For measurements above 1 GHz, the uncertainty in gain is approximately 0.1 dB for antennas with gains between 6 dB and 45 dB. The uncertainty in polarization axial ratio is about 0.05 dB/dB. Below 1 GHz, gain accuracies may degrade to about 0.25 dB for antennas with gains as low as 10 dB.

The facility is also useful for some far-field antenna measurements or for other types of measurements where it is important to know how a transmitted signal varies with distance—millimeter wave propagation studies for example.

Availability:

Two kinds of arrangements can be made to use this facility. The staff of the Electromagnetic Fields Division can perform specified tests or measurements on a reimbursable basis. In this case, the customer has no direct interaction with the facility; all measurements are performed by NBS staff and the customer is issued a test report.

As an alternative, work may be performed on a cooperative basis with NBS staff, and the user is responsible in large part for the accuracy of test results. In either case, arrangements need to be made well in advance and reimbursement is required for the facility use and time of NBS staff involved.

Contact:

Mr. Allen C. Newell, Electromagnetic Fields Division, Room 4065 Radio Building, National Bureau of Standards, Boulder, CO 80303.
Telephone: 303/497-3743.

[redacted]

Automated Manufacturing Research Facility

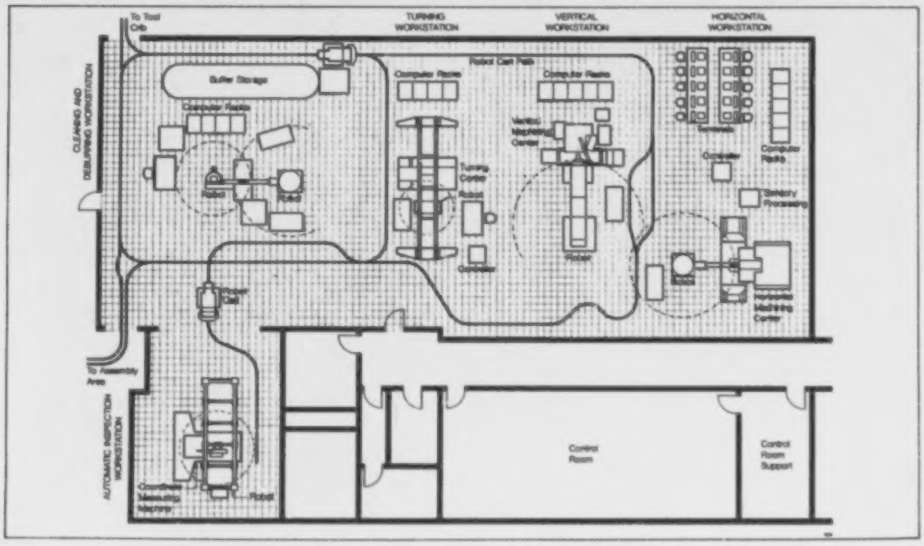
The Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards is a major national laboratory for technical work related to interfaces and standards for the next generation of computer-automated manufacturing. The facility, begun in 1981, will be in full operation by the end of 1986. Initial workstations of the facility are already being used in active research programs by NBS researchers, industrial research associates, guest workers, university personnel, and scientists and engineers from other government agencies.

Capabilities:

The facility currently supports research in machine tool and robot metrology, sensors and sensory processing, robot safety, robot control, software accuracy enhancement of machine tools, process planning and data preparation for machine tools and robots, parts routing and handling, realtime control of robots and aggregations of devices, workstation control, cell control, and materials handling control. It is particularly valuable for studies of interfaces between control modules and among data users. The AMRF is unique in the opportunities it provides for studies of an integrated system of significant size.

The AMRF consists of three machining centers, a coordinate measuring machine, and a cleaning and deburring station, each tended by an industrial robot and served by a materials handling system based on an automated wire-guided vehicle and an internal buffer storage

Automated Manufacturing Research Facility


To Tool Crib
TURNING WORKSTATION
VERTICAL WORKSTATION
HORIZONTAL WORKSTATION
CLEANING AND DEBURRING WORKSTATION
Buffer Storage
Computer Racks
Robot
Robot
Robot Cart Path
Computer Racks
Turning Center
Robot
Controller
Computer Racks
Vertical Machining Center
Robot
Terminals
Controller
Computer Racks
Sensory Processing
Robot
Horizontal Machining Center
Robot Cart
To Assembly Area
AUTOMATIC INSPECTION WORKSTATION
Coordinate Measuring Machine
Robot
Control Room
Control Room Support

system for tools, materials, and work in progress.

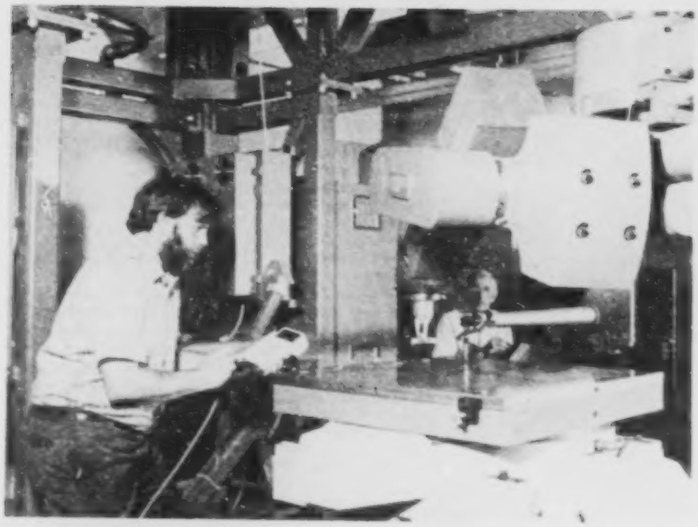
These devices are organized into workstations consisting of a major machine tool, its robot, a variety of sensors, and a workstation controller. Workstation activities are scheduled and coordinated by a cell controller. Two further control levels provide long-range planning and scheduling as well as design and engineering services, such as process planning and offline programming of machine tools and robots. Data, commands, and status information are handled over a network communications system employing a distributed data administration approach.

Availability:

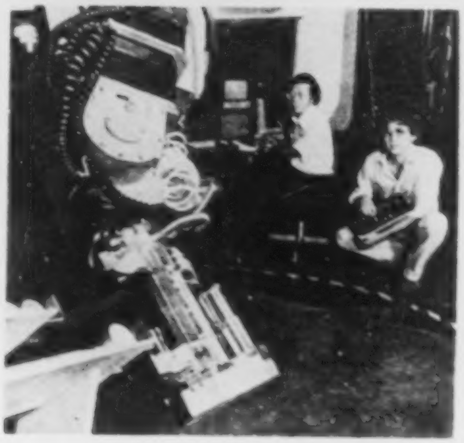
By the nature of the problems addressed, the AMRF is generally best suited for research projects of an extended nature. Most fruitful work to date has involved a close working relationship with NBS which extends for 6 months to 1 year.

Contact:

Dr. Philip N. Nanzetta, Center
for Manufacturing Engineering,
Room B112 Metrology Building,
National Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3421.



Coordinate Measuring Machine in Automatic Inspection Workstation



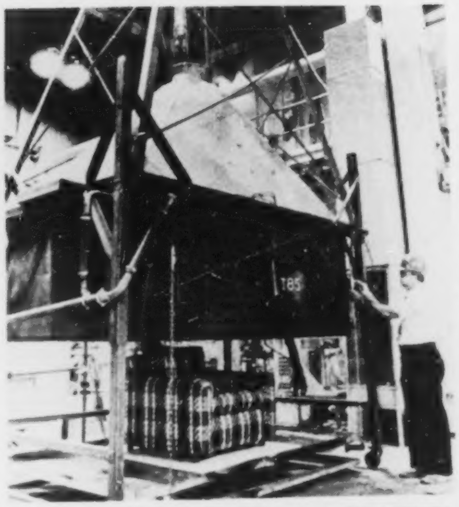
Turning Workstation

Fire Research Facilities

As the federal government's principal fire research laboratory, the Center for Fire Research at the National Bureau of Standards maintains some of the country's best and most extensive fire testing facilities. A substantial portion of NBS' fire tests are performed in a specially-equipped fire research building designed for large-scale fire experiments. The building is 27 m by 57 m. Smoke abatement equipment permits large fire tests to be conducted safely without polluting the environment.

In addition to several individual burn rooms, which are modified from time-to-time to accommodate special NBS testing requirements, the facility also houses several specially designed calorimeters for measuring the rate of heat release from materials and large samples, a new room/corridor facility for studying smoke and toxic gas transport, pilot furnaces, and reduced-scale model enclosures. Also, in 1984 construction began on a two-story "townhouse" for studying fire spread from a burning room, smoke transport between levels, and sprinkler performance.

A new computer-based data acquisition system provides state-of-the-art data collection capabilities for all large-scale fire testing. Up to 300 instruments with scanning rates over 100 channels per second can be dedicated to a single test. During an experiment, real-time, full-color graphics present the data as they are collected, with automatic conversion to engineering units for gas analysis, rate of heat release, temperature, and other measurements.



Heat-Release Rate Calorimeter

Capabilities:

Heat-Release Rate Calorimeters—The Center for Fire Research at NBS pioneered and developed the oxygen consumption methodology for measuring the rate of heat release, and has used it longer and in more devices than any other laboratory. The major benefit of this technique is the independence of the apparatus in measuring enthalpy responses to changes in heat-release rate.

A laboratory-scale calorimeter for measuring the heat-release rate of materials up to 300 mm by 300 mm under external irradiation up to about 100 kW/m^2 is available for fundamental research. Of special interest is the furniture calorimeter used for measuring the rate of heat release of upholstered chairs or furnishings of similar size; this apparatus provides data on the free-burning fire behavior of furnishings.

Room/Corridor Facility—NBS has constructed and used a room/corridor facility to evaluate an analytical model that predicts the transport of smoke and toxic gases from the room of fire origin into the corridor and secondary target rooms. The design of this facility makes it possible to measure the hazards associated with the burning of wall linings or room furnishings by evaluating the rate of heat release, smoke production, and toxic gas generation. The facility is available in its present form or with design modifications for the evaluation of a variety of building contents and furnishings.

Burn Rooms—A standard burn room built to ASTM specifications, 2.4 m by 3.7 m by 2.4 m high, adjoins a large overhead hood which collects the exhaust products from the room fires. The exhaust collection system is calibrated to measure the rate of heat release and the generation rates of smoke and other combustion products from the fire. The burn room is available for developmental and validation studies of mathematical models and for studies of fire performance of furnishings and interior finish materials.

The room fire environment can be characterized in terms of temperature and pressure gradients and the spatial distribution of thermal flux, gaseous combustion products, and smoke. Other measurements permit the calculation of thermal losses to the room boundaries and mass and energy flows from the room. Other smaller burn rooms also are available.

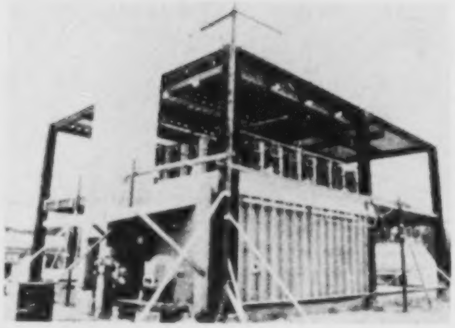
Pilot Furnaces—Two pilot furnaces for evaluating the fire endurance of wall assemblies or floor/ceiling assemblies are available. These furnaces, one capable of handling specimens 2.4 m by 3.0 m and the other 1.0 m by 1.0 m, may be used for research purposes only and cannot be used for code acceptance testing. Typically, fire exposure similar to that specified by ASTM E 119, under carefully controlled conditions of furnace pressure and oxygen concentration, can be carried out routinely. Depending on the parameters required, a variety of other exposure conditions can be applied.

Reduced-Scale Models—NBS facilities are available for reduced-scale modeling of full-scale fire configurations. Physical models offer an economical means of achieving sufficient variation of physical parameters for a generalized understanding of fire behavior. Based on the results of reduced-scale experiments, limited full-scale verification then can be performed.

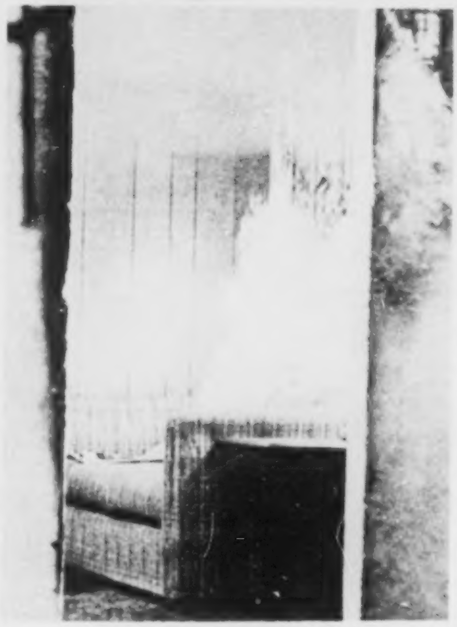
Two-Story Structural Steel Facility—This test structure consists of a two-story, four-bay structural steel frame measuring 9.75 m by 12.2 m. The steel frame is sized to reflect the structure typically found at mid-height of a 20-story building. A manually operated propane burner, with a capacity of 4.4 MW and requiring a 10 horsepower electric blower, is mounted in a masonry wall across one end of one of the bays.

Any of the eight compartments, or combinations thereof, can be enclosed to serve as a furnace or a burn compartment. The top of the structure has a poured concrete deck over steel, while the second story has a poured concrete deck over steel in two of the opposing quadrants. The other two quadrants have no floor. Extensive instrumentation and data acquisition capabilities are available for any part of the structure.

The test frame is available for use as a burn compartment in which products could be burned and the resulting energy and combustion product measured. The bay containing the burner wall can be used as a fire endurance furnace for evaluating walls or floor/ceiling assemblies.



Two-Story Structural Steel Facility Used in Fire Research



Burn Room in Fire Research Facility

Availability:

Industry, university, and government representatives are encouraged to use NBS fire testing facilities on a collaborative or independent basis, with certain restrictions. For safety reasons, NBS staff must closely supervise all use of such facilities.

Contact:

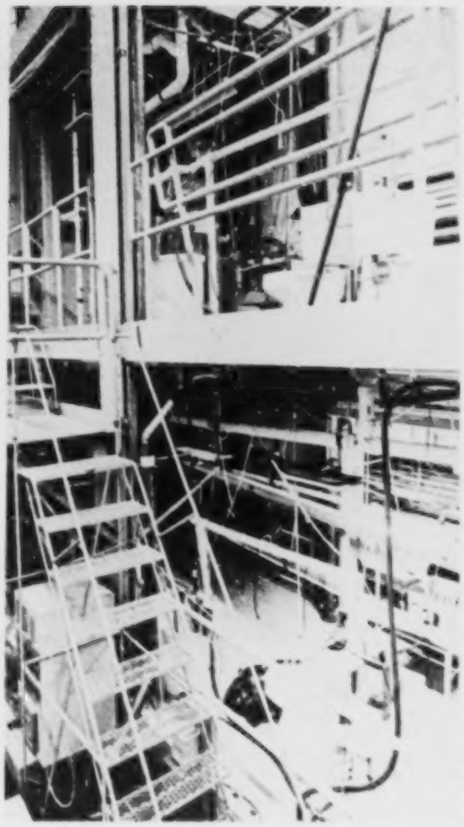
Dr. Jack E. Snell, Center for Fire Research, Room A247
Polymers Building, National Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3143.

Plumbing Research Laboratory

The plumbing research laboratory at the National Bureau of Standards is a five-story, highly adaptable facility capable of simulating the plumbing configurations of a low- to medium-rise building. An appendage to the principal tower allows for the simulation of single-family plumbing systems including a split-level configuration. Data are recorded using a high-speed, preprogrammed data acquisition system which can be programmed to handle both water supply and waste drainage systems.

Capabilities:

The facility allows for the construction of innovative or conventional plumbing systems at each of the five floor levels and the split-level appendage. Water closets, lavoratories, bath tubs, or other devices may be installed and provided with water supply systems, drainage systems, and venting configurations. Each of the fixtures may be activated remotely, either separately or in combination, with operation controlled manually or by computer on a programmed basis. Among the dynamic performance parameters that can be measured are pressures, velocities, and mass flow or volume-discharge rates of air and water, water levels, temperatures, piping strains and stresses, and linear or rotational movements. The facility also can be programmed to provide a measured quantity of water at a given flow rate from a holding tank at the top of the facility to simulate upper-story loading.



Plumbing Research Laboratory

Applications:

The facility is well suited to measure system dynamics of flow and pressure for drain waste and vent (DWV) components under simulated loadings. Positive and negative pressures also can be introduced at various points in the system to determine the plumbing characteristics under these conditions. Recent applications have included experiments to determine if plumbing systems perform satisfactorily with reduced-sized venting.

Availability:

The plumbing research facility is available for collaborative projects and for independent research. It must be operated under the cognizance of the NBS staff.

Contact:

Dr. Lawrence S. Galowin, Building Equipment Division, Room B326 Building Research, National Bureau of Standards, Gaithersburg, MD 20899. Telephone: 301/921-3293.

[redacted]

Large Environmental Chamber

The large environmental chamber at the National Bureau of Standards is 14.9 m by 12.8 m by 9.5 m high. It has an earth floor and may be excavated as needed for building construction. The chamber is one of the largest of its kind, capable of accommodating two-story houses under simulated environmental conditions. This chamber has been used for thermal performance, heating and cooling load measurements, and energy consumption for buildings of different kinds.

Capabilities:

The chamber is capable of automatically maintaining steady and/or dynamic temperature profiles from −45 to 65 °C and humidity from 50 percent RH at 1.7 °C up to 35 °C dewpoint at 49 °C. A wider range of relative humidity (15 to 80 percent) may be obtained manually. Air circulation maintains the temperature variation within the chamber to within ±1 °C. Damper-control return ducts in all eight corners of the chamber permit good air distribution. Supply air is furnished by ceiling diffusers.

Applications:

The chamber is used to measure indoor temperature fluctuation, heat loss and heat gain through the building envelope, energy conservation, moisture condensation, and air infiltration under simulated and dynamically fluctuating outdoor temperature cycles. The chamber has been used to test a wide variety of conventional and special structures and equipment, including military hardware (such as inflatable life rafts, relocatable air-inflatable hospital units, and portable walk-in coolers) under extreme climatic conditions.

Availability:

This facility has substantial potential for use by researchers in industry and universities. Collaborative programs and individual research are arranged through NBS' Building Physics and Building Equipment Divisions.

Contact:

Dr. Tamami Kusuda, Building Physics Division, Room B218 Building Research, National Bureau of Standards, Gaithersburg, MD 20899. Telephone: 301/921-3637.

Large Environmental Chamber

[redacted]

Line Heat-Source Guarded Hot Plate

This 1,000-mm guarded hot-plate apparatus at the National Bureau of Standards measures the thermal conductivity of building insulation. NBS uses the hot plate to provide calibration specimens for guarded hot plates in other laboratories. It also is used to investigate edge heat loss from thick thermal insulation materials. This facility is the only one of its kind in the world which will permit low-density thick insulation to be measured with an error rate less than 0.3 percent.

Capabilities:

This apparatus has a test temperature range of 200 °C for the hot plates and −20 °C for the cold plates. The apparatus permits measurement of vertical and horizontal heat flow to simulate the heat transfer through ceilings and floors respectively. This apparatus operates within its own carefully controlled temperature and humidity environment shielded by an insulated aluminum enclosure. This facility provides for absolute measurement of thermal resistance of thick- and low-density test specimens used as transfer standards. These standards are used to calibrate or verify heat flow meter (ASTM C508) or guarded hot-plate (ASTM C177) equipment.

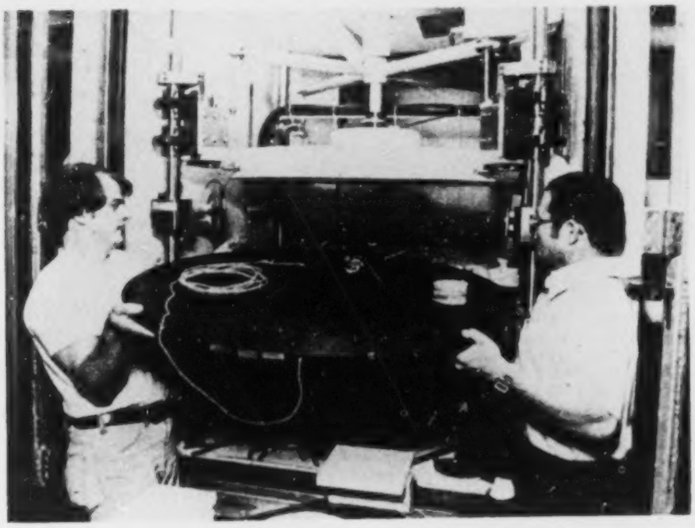
Availability:

This apparatus is available for use by those outside NBS, but it must be operated by NBS staff. Collaborative programs may be arranged through the NBS Building Physics Division.

Contact:

Mr. Thomas K. Faison, Building Physics Division, Room B114 Building Research, National Bureau of Standards, Gaithersburg, MD 20899. Telephone: 301/921-3501.

Line Heat-Source Guarded Hot Plate



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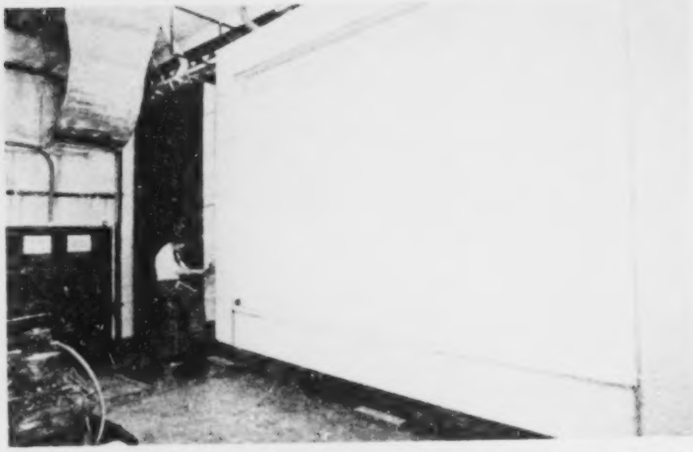
Calibrated Hot Box Facility



This National Bureau of Standards apparatus measures the heat transfer coefficient of full-scale building wall sections. Designed in accordance with ASTM Standard C-976, it consists of two large heavily insulated chambers—an environmental chamber and a climatic chamber—each with one open side. Indoor and outdoor conditions are simulated in the chambers, which are 4 m high, 5.5 m wide, and 1.6 m deep. The open test section measures 3 m by 4.6 m. A well-insulated frame supports the wall specimen that is clamped between the open sides of the two chambers.

Capabilities:

This facility is the only one of its kind designed to perform simultaneous dynamic transfer measurements of air, moisture, and heat during simulated winter and summer conditions under steady state and dynamic driving functions. While the environmental chamber temperature and humidity are maintained to simulate a relatively steady and narrow range of indoor conditions, the climatic chamber can attain temperatures ranging from −40 to 65 °C with relative humidity between 20 to 80 percent. The apparatus measures the performance of homogeneous or composite walls having a range of thermal resistance from 0.35 to 8.8 m^2 C/W, air leakage rates up to 255 m^3/hr, and moisture transfer rates up to 1.4 kg/hr. It accommodates wall specimens up to 0.6 m thick and up to 700 kg/m^2 in weight per unit area.

Applications:

NBS will be using the facility to develop standard test methods to evaluate dynamic thermal performance of full-scale walls under cyclic temperature, humidity, and air pressure conditions. Currently these test methods do not exist. The building industry and government agencies are seeking reliable evaluation techniques for wall thermal mass, especially to predict energy consumption of buildings with heavy mass effects in comparison to standard wood-frame buildings.

Using this apparatus NBS will provide industrial laboratories and others with standard reference test specimens representing selected types of walls of different thermal conductances and thermal mass under steady and dynamic conditions. NBS has participated in round-robin test activities with domestic and overseas thermal insulation laboratories.

Availability:

This apparatus is undergoing calibration tests and will be available for external use in the spring of 1985. The facility is expected to provide a unique opportunity to measure simultaneous transfer of air, moisture, and heat through wall and roof specimens with openings for windows and doors. While it is available for use by those outside NBS, this apparatus must be operated by NBS staff.

Calibrated Hot Box Facility

Contact:

Mr. Thomas K. Faison or Mr. Douglas Burch, Building Physics Division, Room 114 Building Research, National Bureau of Standards, Gaithersburg, MD 20899.
Telephone: 301/921-3501.

[redacted]

Tri-Directional Test Facility

The tri-directional test facility at the National Bureau of Standards is a computer-controlled apparatus capable of applying cyclic loads simultaneously in three directions. It is used in examining the strength of structural components or assemblages under the application of a variety of loading phenomena such as earthquake or wind. This is one of the largest such facilities in the world, both in terms of its high-load capacity and its capability to handle large, full-scale specimens.

Capabilities:

The facility can apply forces and/or displacements in 6 degrees of freedom at one end of a specimen. The other end of a specimen is fixed. Specimens up to 3.3 m high and 3 m in length or width may be tested. The 6 degrees of freedom are translations and rotations in and about three orthogonal axes. The forces are applied by seven closed-loop, servo-controlled hydraulic actuators that receive instructions from a computer. Operating under computer control, the facility simultaneously maintains control of the load and/or displacements in each of the three orthogonal directions. Loads may be applied up to 2,760 kN in the vertical and about 890 kN on each of the two horizontal directions.

Applications:

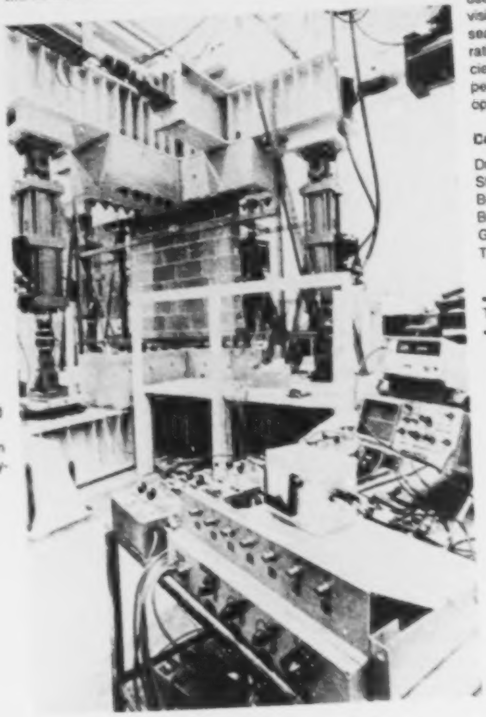
The tri-directional test facility is limited only by the size of the test specimen. Loads may be cyclic or unidirectional depending on the type of loading condition being simulated. Currently the facility is being used to study masonry shear walls subjected to reversed cyclic lateral loading with a combination of boundary conditions and vertical loads. This facility supports NBS' role in developing research for seismic design and construction standards in the National Earthquake Hazards Reduction Program.

Availability:

The tri-directional test facility is used by the NBS Structures Division in a variety of NBS research projects and collaborative projects with other agencies. It also is available for independent research, but must be operated by NBS staff.

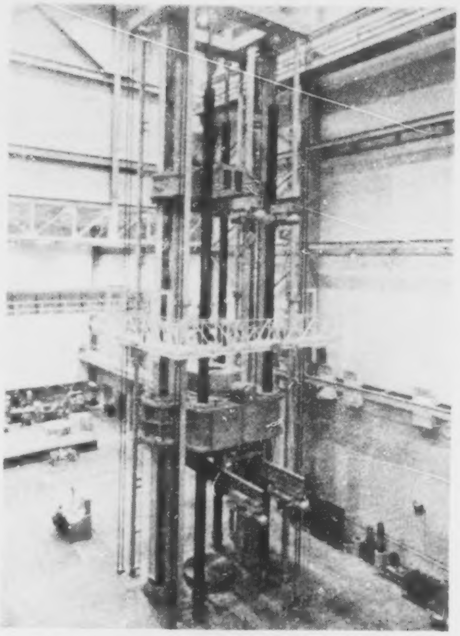
Contact:

Dr. Edgar V. Leyendecker,
Structures Division, Room B168
Building Research, National
Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3471.



Tri-Directional Test Facility

Large-Scale Structures Testing Facility



Universal Testing Machine in the Large-Scale Structures Testing Facility

The large-scale structures testing facility at the National Bureau of Standards consists of a universal testing machine to apply tensile and compression loads to full-scale test specimens. A 13.7-m-high reaction buttress is currently under construction which will allow use of both the testing machine and the buttress to apply combinations of vertical and lateral loads to large-scale test specimens.

Capabilities:

The universal testing machine portion of the facility is a hydraulically operated machine of 53.4 MN capacity and is one of the largest in the world. It has a height of 23.8 m above the floor level. It tests large structural components and applies the forces needed to calibrate force measuring devices of large capacity. The machine can apply axial forces of 53.4 MN to column sections or fabricated members with lengths up to 17.7 m. The reaction buttress is capable of applying lateral loads of 4.5 MN at heights varying from floor level to 12.2 m above the floor level.

Applications:

The large-scale test facility may be used to test specimens under combinations of vertical and lateral load. Currently a testing program is underway to evaluate performance of concrete columns up to 1.5 m in diameter and 9.1 m in height. The universal testing machine portion of the facility may be used conveniently to test large tensile and compression specimens and to calibrate large-capacity force measuring devices.

Availability:

Collaborative or independent programs for this test facility are arranged through the NBS Structures Division. The facility must be operated by NBS staff.

Contact:

Dr. Edgar V. Leyendecker,
Structures Division, Room B168
Building Research, National
Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3471.

Acoustic Reverberation Chamber

This facility at the National Bureau of Standards is used to determine sound absorption coefficients of building materials as well as sound power emitted from various equipment, such as air-conditioners and household appliances. The facility is a vibration-isolated, shell-within-shell type structure of reinforced concrete with inside dimensions of 9.1 m by 7.6 m by 6.1 m creating a volume of 425 m^3. The chamber's interior and its surrounding 1-m-wide air envelope are air-conditioned and humidity controlled and provided with conduits for communication and data acquisition. The chamber is equipped with adjustable, variable speed, rotating vanes to create a uniform sound-field distribution. Numerous pipe-sleeve openings of various sizes are available for other specialized uses such as conduit for hydraulic, pneumatic, fuel, or exhaust lines.

Capabilities:

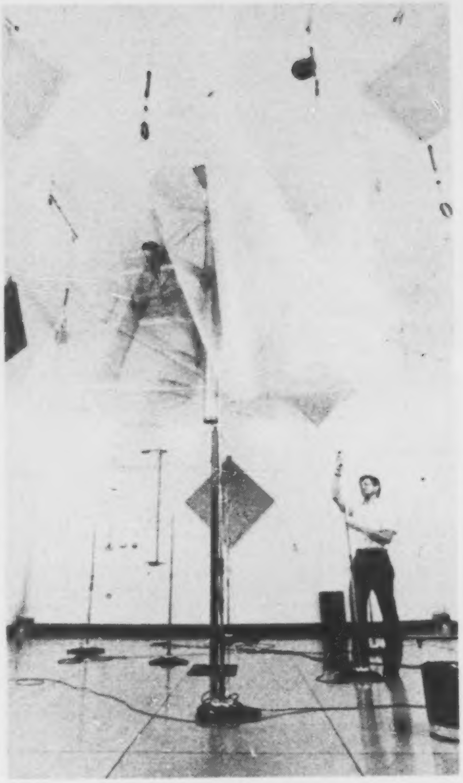
The chamber is designed to provide a highly diffuse sound field in the frequency range of 100 to 10,000 Hz. The sound pressure is sampled by an array of 12 microphones, six mounted on stands placed on the floor and six suspended from booms attached to the ceiling. The booms may be rotated to give a wider range of microphone locations. Also, the facility is equipped with eight microphones mounted at each of the trihedral corners of the chamber—a unique characteristic among U.S. facilities. The loudspeaker used to determine the decay measurements and the microphones are connected to a computer in the adjacent laboratory.

Applications:

The chamber is used to develop measurements of sound absorption coefficients and to determine sound power of sound sources. It supports basic research to define the acoustical parameters for building materials and spaces and to develop and validate mathematical models for predicting acoustic field. The chamber is operated and maintained by the NBS Building Physics Division.

Availability:

This facility has substantial potential for use by researchers in industry, universities, and other government agencies. Scheduling arrangements for collaborative programs and individual research are handled by the Building Physics Division.



Acoustic Reverberation Chamber

Contact:

Dr. Simone L. Yaniv, Building Physics Division, Room A105 Sound Building, National Bureau of Standards, Gaithersburg, MD 20899.
Telephone: 301/921-3783.

Acoustic Anechoic Chamber

This facility of the National Bureau of Standards is used to determine the sound power emitted by sound sources as well as how much sound power flows in a given direction. It also is used to calibrate acoustical equipment such as microphones and loudspeakers. The facility is a vibration-isolated, shell-within-shell structure 6.7 m by 10.0 m by 6.7 m, creating a volume of 450 m^3. The absorptive treatment consists of glass wool wedge modules installed on all six inner surfaces of the room. Access to equipment within the room is provided by a wire mesh floor. Additional accessories in the room include communication line outlets and rigid supports for equipment on all six surfaces. Air-conditioning ducts are acoustically treated. Humidity control provides 45 percent relative humidity within ±5 percent.

Capabilities:

The chamber is designed to provide a highly anechoic sound field. The walls of the chamber are designed to absorb 99 percent or more of the normally-incident sound energy at all frequencies above 45 Hz. The chamber's airflow can be cut off if a lower background sound level is required.

Applications:

The chamber is used to develop procedures for measuring sound power, to determine the direction of sound intensity, and to calibrate acoustical instruments. The chamber also can be used in psychoacoustic studies. It supports basic research to define the acoustical parameters required for the development of mathematical models for predicting acoustical fields.

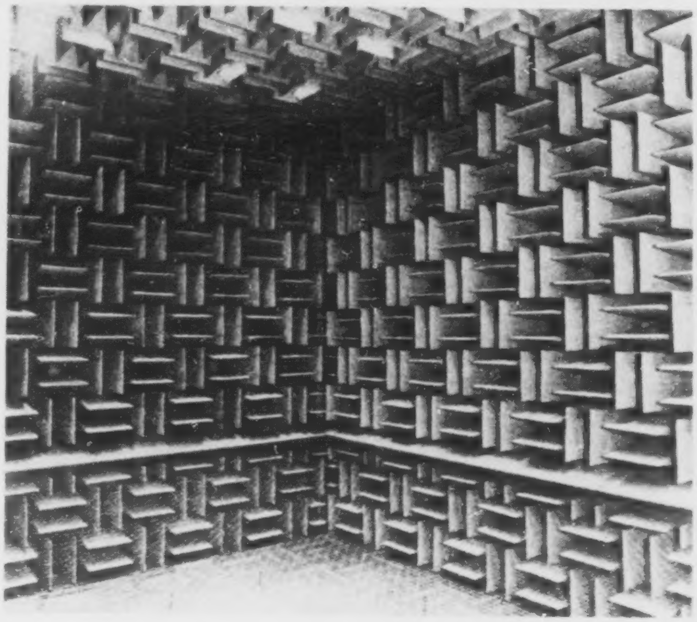
Availability:

This facility has substantial potential for use by researchers in industry, universities, and other government agencies. Scheduling arrangements for collaborative programs and individual research are handled by the NBS Mechanical Production Metrology Division.

Contact:

Mr. Daniel R. Flynn, Mechanical Production Metrology Division,
Room B106 Sound Building,
National Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3565.

Acoustic Anechoic Chamber



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Network Protocol Testing and Evaluation Facility

The Network Protocol Testing and Evaluation Facility at the National Bureau of Standards consists of eight laboratories for research in the design, implementation, and testing of computer network protocols. The laboratories are used to advance measurement methodologies for computer networks. A variety of communications technologies and applications environments have been developed for cooperative research and testing under conditions appropriate for both current and emerging technologies. These research efforts support the development of international standards for open systems interconnection to enable computer systems of different manufacturers to be interconnected for computer-to-computer communication.

Research in developing prototype implementations and testing techniques is carried out cooperatively with federal agencies and industry.

Capabilities:

Network Protocols—Prototype implementations of middle- and high-level protocol standards are developed and tested over a commercial X.25 public data network, the Department of Defense data network, and a local area network based on IEEE (Institute of Electrical and Electronics Engineers) standards. Automated techniques are used to develop formal descriptions and reference implementations of protocols. Automated testing tools have been developed to measure prototype implementations against reference implementations.

Satellite Communications—Protocols are developed and tested over satellite communications where very high band width and long propagation delays affect performance.

High-Speed and Multiprocessor Networks—Protocols are developed and tested over networks that transfer data at very high communication speeds (50 to 100 megabits per second).

Videotex—Techniques and methods are developed to test implementations of the North American Presentation Level Protocol Standard (NAPLPS) for videotex applications.

Public Data Networks—Verification techniques are available for testing equipment and services for conformance to FIPS 100, Interface Between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Operation with Packet-Switched Data Communications Networks (based on X.25 standard of CCITT).

Network Security—Encryption techniques are developed and tested to protect data transmitted in networks, manage secret cryptographic keys, provide for personal identification of users, and provide for data integrity.

Local Area Networks—Tools and techniques are developed to test the correctness and performance of different local area network technologies, including carrier sense multiple access with collision detection (CSMA/CD) and token bus access methods.

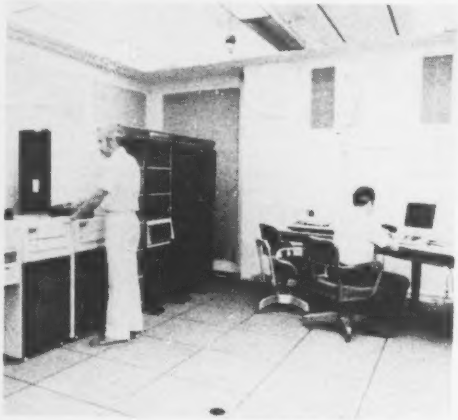
Computer-Based Office Systems—Message and document interchange protocols are developed and tested in environments suitable for communicating word processors and desktop computers.

Availability:

Cooperative research in networking involves more than 30 computer manufacturers, 10 other federal agencies, and five research laboratories in other countries. Collaborative programs are arranged through the NBS Center for Computer Systems Engineering.

Contact:

Mr. Robert P. Blanc, Center for Computer Systems Engineering,
Room A231 Technology Building,
National Bureau of Standards,
Gaithersburg, MD 20899.
Telephone: 301/921-3817.



Network Protocol Testing and Evaluation Facility

Reprint Series
5 March 1982, Volume 215, page 1189

SCIENCE

Cooperation in R & D: Whose Responsibility?

Spurred by competitive and financial pressures, U.S. research laboratories in universities, industry, and government are searching for collaborative agreements to improve their performance. Many successful arrangements are being expanded and new ideas put forward. The National Bureau of Standards (NBS) has had considerable experience in cooperative research arrangements, and some thoughts based on our experience may be useful to others.

While some U.S. institutions are finding it possible to agree on long-term and comprehensive multimillion-dollar research ventures, we have found that cooperative efforts need not be long-term nor restricted to "big ticket" items. The big national research facilities must be shared, as we share our research reactor, synchrotron radiation source, and other facilities, but these need not be the models for all cooperative ventures. Our Research Associate Program has fostered a variety of useful cooperative research programs, many of which require little in the way of unique facilities and are narrow in scope. Each agreement has been tailored to fit the work at hand and the capabilities and goals of the participant.

Over the past decade, NBS initiated a series of research projects to improve our knowledge of the properties of liquefied natural gas (LNG) mixtures, containment materials, and measuring techniques. About half the work was funded by relatively small-scale cooperative programs with industry, particularly under the aegis of the American Gas Association. At one point we put together a 19-member consortium of natural gas users, importers, and utilities for a single project to develop a good equation of state for LNG. One of the most successful projects, backed by NBS, the American Gas Association, the Maritime Administration, and the American Bureau of Shipping, was simply to produce a well-documented, easy-to-use handbook of data for LNG users. Typically, it took 9 to 18 months to make the arrangements for a project in the LNG program. Likewise, we recently announced a major cooperative program with the American Society for Metals to collect evaluated alloy phase diagram data and make the data available through a computerized information system.

These are only two examples of the variety of our joint research ventures. About 100 industrial research associates and 40 postdoctoral fellows are working today at NBS. More than 325 professors and students are stationed in NBS laboratories each year under various guest worker arrangements. We have education agreements with 100 universities and colleges and joint research programs with the Electric Power Research Institute, the Gas Research Institute, the American Dental Association, the American Society for Testing and Materials, and others.

In carrying out cooperative research programs, one must be persistent, attentive to detail, and involve both the technical staff and managers in the initial detailed formulations and the later critiques of progress. In all our agreements there has been no substitute for the involvement of bench scientists and engineers. Laboratories wishing to collaborate in research should seek the advice of all potential participants, whether they are in industry, universities, or government. At NBS all research managers are encouraged and expected to make such interaction a way of life. That concern is manifested by daily contact with university and industry peers and users and by a variety of formal evaluation panels involving scientists and engineers selected by the National Academy of Sciences and the National Academy of Engineering. This kind of regular interaction fosters an environment that is receptive to cooperative research.

The pluralistic nature of American society presents a real variety of opportunities for cooperation, and these opportunities should be imaginatively explored. It is up to managers and researchers to be ambitious and innovative in their planning for cooperative research and to have the will to work out seemingly small but nevertheless crucial details of mutual understanding.—ERNEST AMBLER, *Director, National Bureau of Standards, Washington, D.C. 20234*

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11/16/87

MALCOLM BALDRIGE
NATIONAL QUALITY AWARD

Program Fact Sheet

Authority for Awards

- Public Law 100-107, the Malcolm Baldrige National Quality Improvement Act of 1987, signed by President Reagan on August 20, 1987, establishes a U.S. National Quality Award.
- Secretary of Commerce and National Bureau of Standards (NBS) are given responsibilities to develop and administer Awards with funding from the private sector.

Purpose of P.L. 100-107

- Promote quality awareness in U.S. business
- Recognize quality achievements of U.S. companies
- Publicize successful quality strategies

Key Provisions of P.L. 100-107

- Categories for Awards: (1) companies or subsidiaries; (2) small businesses; and (3) service companies. Up to two Awards may be given each year in each of these categories.
- Criteria for Qualification: Apply in writing to Director, NBS; and permit rigorous evaluation.
- Awards: Medal bearing inscription "Malcolm Baldrige National Quality Award" presented by the President or the Secretary of Commerce. Award recipients may publicize and advertise based upon Awards.
- Award Examination: NBS shall rely upon a Board of Examiners which shall conduct reviews and site visits.
- Technology Transfer: NBS Director shall ensure feedback to applicants and publicize successful quality improvement strategies.
- Award Program Oversight: Secretary of Commerce shall appoint prestigious Board of Overseers to review Award process.
- Funding: Secretary of Commerce is authorized to seek and accept gifts and to impose fees upon applicants.

Award Program Plan

- Presentation of Awards
  - Awards will be presented by the President at an Awards ceremony in November 1988.
- Eligibility
  - Businesses incorporated and located in the U.S., and either privately or publicly owned
  - Categories:
    - companies--manufacturers of goods, mining, construction, agriculture (SIC Codes 01 to 39)

  - subsidiaries--business units or divisions of companies
  - service companies--defined by SIC Codes 40 to 89
  - small businesses--independently owned, 25 to 500 employees (note: classification as service or company is determined by larger percentage of sales)
- Criteria
  - Includes quality process, continuous quality improvement, and customer satisfaction
  - Specific examination areas: (1) leadership; (2) information and analysis; (3) planning; (4) human resource utilization; (5) quality assurance of products and services; (6) quality improvement results; and (7) customer satisfaction
- Application Process and Review:
  - (1) Written application responding to detailed questions in seven criteria areas.
  - (2) Screening of each application by three Examiners to select finalists.
  - (3) Site visit and customer satisfaction examinations of finalists. Detailed site visit requirements will be set by the Board of Examiners.
  - (4) Board of Examiner review of all data and information to recommend Award recipients.
- Technology Transfer
  - NBS will create an Affiliates Program with professional societies and trade associations to serve as an avenue to help ensure that the findings in the Awards Program are available for use in training, education, and certification programs of these organizations.
  - NBS will provide feedback to applicants based upon evaluations carried out by the Board of Examiners.
  - NBS will develop linkages to university programs to ensure that the findings in the Awards Program become available for inclusion in university curricula.
  - NBS will develop linkages to regional Quality Councils, state, and local organizations concerned with quality.
- Examiners
  - NBS is seeking highly qualified candidates to serve as Examiners. Final selections will be made on the basis of overall expertise and experience. The Examiner Board will reflect balance of expertise among services and manufacturing.
  - A training/scoring program will be developed for Examiners to ensure equity and consistency of evaluations.
  - Examiners will be compensated and reimbursed for expenses according to terms under development.
  - Examiners will sign nondisclosure agreements to protect trade secrets. Assignments of Examiners to application review and site visit will be made based upon screening for potential conflicts of interest.

- Timetable
  - Applications will be available from NBS by February 15, 1988.
  - Applications must be filed by May 1, 1988. An application fee of not more than $1500 will be charged. The exact fee will be set when applications become available.
  - Applications will be reviewed and site visits conducted between May 1 and September 30, 1988. Finalists will be notified of site visits and site visit fees at least three weeks in advance of visits.
  - An Award Ceremony will be held in mid November 1988. Recipients will be notified approximately six weeks in advance of the ceremony.
- Funding of Award Program Development
  - The Malcolm Baldrige National Quality Award Foundation will be established to raise funds to support the development of the Award Program.
  - A prestigious Board of Trustees will be appointed to lead the fund raising campaign.
- National Quality Award Program Development Review
  - NBS is working with the American Society for Quality Control, the American Productivity Center, other organizations, and individuals to develop the Award Program, to review plans, and to identify quality leaders to participate in the Program. NBS will ensure a broad base of review before the first cycle of Awards begins.

Award Program Contact

Dr. Curt W. Reimann
Malcolm Baldrige National Quality Award
National Bureau of Standards
Gaithersburg, MD 20899
(301) 975-2036

National Bureau of Standards

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Foreword

Looking at where we are today and where we want to be—both for the National Bureau of Standards as an institution and the nation as a whole—one basic fact keeps coming to mind. Our knowledge and technology are this country's major asset and advantage, both in ensuring domestic strength and health and in competing with other nations. That means we must make the most of our research resources—our equipment as well as our people. Cooperation in research and development is one obvious answer. This is something that we have been doing since NBS was established in 1901 as the nation's physical sciences, measurement, and engineering laboratory. As an agency of the Department of Commerce, NBS has made cooperation with industry a way of doing business, and it has served as a model for cooperative arrangements which are becoming more popular today as industry, universities, and government form research partnerships all across the country. We are using cost-sharing arrangements with others whenever and wherever possible, and this brochure provides a number of examples of our cooperative endeavors.

But cooperation in research and development will not be enough. Doing the research is only half the battle. The results of this research must be incorporated into new ideas, new processes, and new products. New technology must diffuse throughout our industries, and diffuse more rapidly than it does now. We need to think about cooperation in the transfer and diffusion of technology in the same way that we have addressed cooperation in research and development.

NBS is taking a lead here, too. We spend a good deal of time with visiting scientists, engineers, and managers from industrial firms. About 200 of these specialists work at NBS each year as research associates, with their sponsoring organizations paying their salaries. They come to NBS to conduct research, but they also come to learn how they can put our work to use.

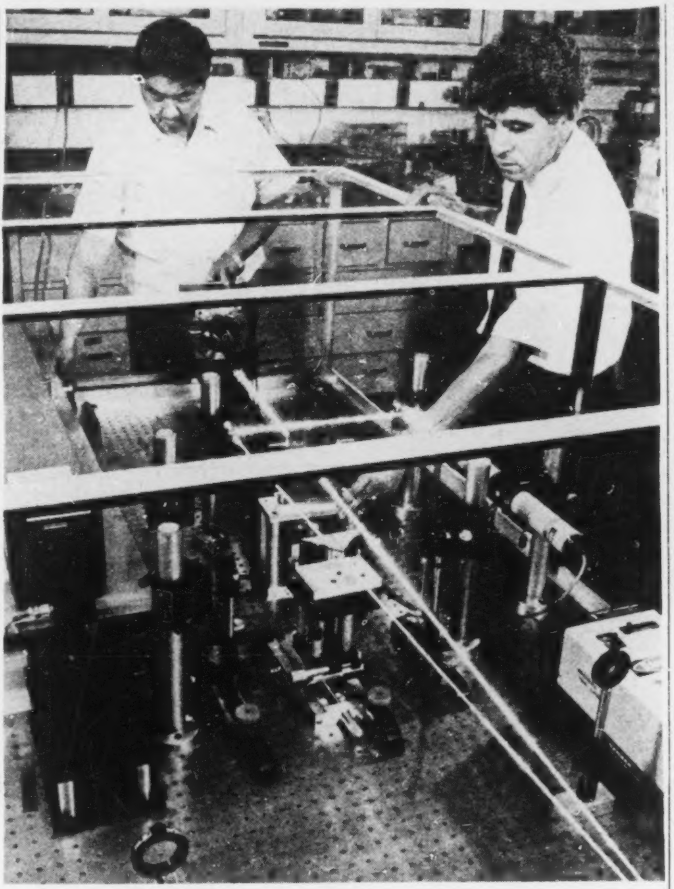
We have taken other steps to encourage technology transfer, by holding literally hundreds of conferences, workshops, and seminars each year, by encouraging our staff to publish results of their work as broadly as possible, and by working actively with professional and technical societies and standards organizations. We are using videotapes to explain our research so that others can take advantage of our work. We now are making many of our databases and experts available through computer networks, and we are considering expanding this service so that industry will be able to tap into even more of our information.

We will continue to look for new outlets, new ways to disseminate our research results and services throughout the U.S. economy. I am convinced that as a nation we must all join together to develop creative ways to transfer technology, just as we now seem to be developing the capacity to conduct research together. There is not much choice if we want this country to be competitive in a changing world economy.

Ernest Ambler.

Ernest Ambler
Director

Institute for Materials Science and Engineering



From ceramic tiles that shield the space shuttle to dental adhesives which replace metal fillings, new materials are revolutionizing technology and everyday life. NBS is at the forefront of materials technology with its broad-based research effort conducted by the NBS Institute for Materials Science and Engineering (IMSE). The Institute provides measurements, data, standards, reference materials, and other technical information regarding materials to industry, government agencies, universities and other scientific organizations. IMSE research supports development of new and improved materials which can be used safely, efficiently, and economically.

To determine how polymers behave during processing, polymer scientists Charles Han (left) and Isaac Sanchez use a forced Rayleigh scattering instrument to study phase separations in polymer blends.

Among the materials of the future are advanced high-performance ceramics, which have unique properties that make them well-suited for use in electronics, sensors, cutting tools, biomedical devices, and advanced heat engines. The Institute for Materials Science and Engineering has begun to investigate the relationships among the synthesis, microstructure, properties, and performance of these ceramic materials. In their initial work, researchers are emphasizing new chemical approaches to synthesizing the submicron, multicomponent powders needed by industry to produce such complex ceramics. They have established laboratory facilities to study the synthesis and characterization of advanced ceramics. Other researchers are examining various properties of finished ceramics and developing a unique program to measure their high-temperature wear characteristics.

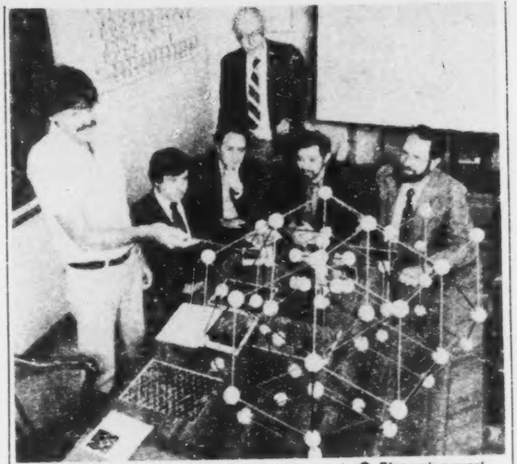
Another class of advanced materials is polymer-matrix composites. Polymers reinforced with high-strength fibers such as graphite or glass have outstanding strength and stiffness for their weight. They are now found extensively in aerospace applications and will be used increasingly in automobiles and construction. The Institute is developing measurement methods to investigate and control composite processing to aid industry in controlling product quality while increasing production efficiency. IMSE is also investigating the mechanisms by which fiber-reinforced composites fail. The test methods and data produced by this program should lead to improved composite materials and better ways to predict the materials' useful service lives.

One of the fastest growing segments of the U.S. synthetic polymer industry is the production of polymer blends, which are mixtures of two or more polymers. These materials are particularly useful as engineering plastics designed to replace metals in products such as gears, pumps, and machine housings. When a polymer blend is processed, the component polymers separate into phases of different compositions, affecting many of its useful properties. The Institute's polymer blends processing program is focused on measurement methods, data, predictive models, and general theoretical descriptions that will form a scientific basis for optimizing control of blend processing. Researchers will use the small-angle neutron scattering (SANS) facility at the NBS research reactor to study the mechanism by which polymers separate from each other.

In addition to advanced ceramics and polymers, electro-optic materials help perform many of the dream feats of forward-thinking engineers. IMSE has begun a program to measure the optical properties of thin-film materials and to study their dependence on processing characteristics. This research will contribute scientific knowledge to the ongoing effort to improve the performance of materials in optical information-processing devices and systems.

In the future, many products made of advanced materials will be produced in automated manufacturing facilities. These facilities will use nondestructive evaluation (NDE) techniques to monitor product quality. Advanced NDE techniques can now monitor important material properties and product parameters. The Institute's NDE program is developing the science base, measurement methods, and standards that will be needed to use NDE for process control in automated manufacturing plants.

The trend toward automated manufacturing is also expected to affect welding. NBS collaborated with industry to establish the American Welding Institute (AWI), which will study and disseminate information about advanced welding technology. One of AWI's high-priority programs will focus on automated welding. NBS will study how flaws are formed during this welding process by conducting controlled solidification experiments in



▲ Discussing quasicrystal structures in alloys are (l. to r.) Daniel Shechtman, Israel Institute of Technology; Frank Biancaniello, NBS; Denis Gratias, National Science Research Center, France; John Cahn, NBS; Leonid Bendersky, Johns Hopkins University; and Robert Schaefer, NBS. The discovery of quasicrystal structures in materials challenges a 100-year-old theory of crystallography, and the existence of quasicrystals may make it possible to produce materials with radically different properties.

model materials. The experiments will use acoustic emission and ultrasonic techniques to detect flaws as they are formed in the welded material. These experiments should lead to better control of defect formation, more effective feedback control for thick section weld automation, and improved weld efficiencies for specific processes.

To provide the science base for the materials of the future, the Institute organizes its research around four technical "themes": materials processing, microstructure characterization, properties, and performance. Scientists from each IMSE division plan and coordinate activities in each of these areas.

For example, there is a coordinated effort within the Institute to measure, collect, and evaluate phase diagram data for the processing of metal alloys, ceramics, and polymer-blend materials. This information is used in the development of new materials and the design of new materials processes. The Institute, in collaboration with professional societies, periodically publishes phase diagrams for alloys and ceramics and makes them available to researchers and industrial users. A large body of evaluated data is being converted into computerized files so that it will be available to users through on-line access. The Institute's phase diagram work is carried out cooperatively with the American Society for Metals, the American Ceramics Society, and the Society of Plastics Engineers. Experimental results for metals, ceramics, and plastics are compiled and evaluated by authorities in 35 data centers throughout the world. In addition to providing phase diagram data, the Institute carries out experimental and theoretical research in support of the data program.

An example of the Institute's activity in microstructure characterization is the work carried out at the SANS facility. This facility is used to study microstructure and flaw development in new structural ceramics, to observe precipitation transformations in supersaturated metallic systems, and to characterize molecular structure and conformation in polymer blends. Similar work will be carried out with the NBS/Naval Research Laboratory beam lines at the National Synchrotron Light Source at Brookhaven National Laboratory. Researchers will use real-time topography for kinetic studies of solidification; small-angle x-ray scattering to measure block copolymer structural features; and interface/inelastic spectroscopy for characterizing multilayer metal-metal oxide coatings.

Research on the properties of materials focuses on wear characterization, measurements, and standards for metals, ceramics, and polymer-matrix composites. Researchers characterize metal-to-metal wear under both clean and abrasive conditions as well as the wear of lubricated surfaces. They develop measurement methods for wear-resistant materials and provide reference materials for calibrating wear test equipment. Institute scientists are investigating the erosion of refractory materials by experimentally observing the effects of single-particle indentation. Their research has also shown that the wear of a polymer-matrix composite is influenced by ambient liquids which soften the matrix.

Performance is a crucial characteristic of all materials. A major materials performance problem is environmentally induced cracking. For example, stress corrosion can cause cracking in engineering alloys, hydrogen embrittlement can crack high-strength steels, cracking in glasses and ceramics is often induced by water vapor, and environmental stresses can crack ethylene-based plastics. Toward the goal of reducing such damage, institute researchers establish the basic mechanisms of the cracking processes and develop test methods to determine the failure resistance of various materials.

As part of its general program, the Institute operates several large facilities, which are used extensively by guest scientists and research associates from academia and industrial research institutions from across the country. One is a nuclear reactor dedicated to materials and radiation standards research. Another is a metals-processing facility capable of modifying surfaces with electron beams and by laser melting, as well as providing measurements of sample quality and microstructure. Together with the Naval Research Laboratory, the Institute has led an effort to construct hard radiation branch lines at the National Synchrotron Light Source. This facility permits unique experimental work in materials characterization.

The Institute is also developing a cold neutron source facility for advanced materials research. The facility is being designed to contain a low-background radiation experimental hall and up to 15 new instrument stations. It will be managed and operated as a national research facility for industrial, university, and government scientists.

Cold neutron beams can augment research in virtually every branch of materials science. Some of the experiments planned for the new facility will focus on the magnetic properties of new advanced alloys, the growth of

Chemist Kay Hardman-Rhyne conducts small-angle neutron scattering experiments at the 20-megawatt NBS research reactor to observe crystal structure and microdefects in ceramics.

Metallurgist Joanne Murray displays a typical alloy phase diagram. Such diagrams are used in the development of new materials and the design of new materials processes.

cracks and nature of voids in new advanced ceramics, the distribution of dopants in advanced semiconductor materials, development of new catalytic materials for petroleum refining, and measurement of the size and shape of engineered biomolecules.

In addition to managing and carrying out these facilities and programs, the Institute supports fundamental theoretical work in phase stability and materials fracture. This work is basic to all of its technical programs and to materials science research throughout the United States.

Many of the Institute's prominent research activities are carried out in cooperation with industrial organizations which fund the work of research associates at the Bureau. For example, Exxon has supported research in characterizing polymer blends with small-angle neutron scattering. General Electric has used NBS' unique time domain dielectric spectrometer for polymer measurements. Martin Marietta has cooperated in characterizing resins used on the space shuttle. Ongoing cooperative programs involve:

☐ The American Society for Metals—evaluation and dissemination of computerized alloy phase diagrams and bibliographic information worldwide with funding support from industry.

☐ The American Ceramic Society—establishment of computer access to phase diagrams and dissemination of phase diagrams of interest to ceramists. The American Ceramic Society will develop industry support and disseminate the phase diagrams and related information.

☐ The Society for Plastics Engineers—development and dissemination of data on thermodynamic behavior of polymer blends. This information will be published through the National Standard Reference Data System at NBS.

☐ The American Iron and Steel Institute—research aimed at development of process control sensors for the steel industry. The joint program concentrates on rapid on-line measurement of temperature distributions and automatic detection of porosity in hot steel.

☐ The National Association of Corrosion Engineers (NACE)—provision of evaluated corrosion data on alloys and other materials. NBS supplies technical guidance and NACE develops program and funding support from industry.

☐ The American Dental Association—development of dramatically improved tooth restorative adhesives and more effective fluoridation treatments based on understanding of tooth mineral phase diagrams. This research is part of a 58-year-old cooperative program partly supported by the National Institute of Dental Research.

☐ The American Welding Institute (AWI)—establishment of the AWI/NBS Welding Data Bank for rapid dissemination of welding data to U.S. industry and improvement of narrow gap, thick plate welding processes in order to increase industrial productivity.

☐ The Welding Research Council—development of improved weld procedure qualification methods.

☐ The Joint Committee on Powder Diffraction Standards/International Centre for Diffraction Data (JCPDS/ICDD)—critical evaluation of powder diffraction data, measurement of reference data, and dissemination of results. The JCPDS/ICDD provides funding support through sales of the Powder Diffraction File. They also disseminate publications and a computer file from the Crystal Data Center maintained by NBS.

National Engineering Laboratory

KEEP UPRIGHT
DO NOT DROP

From basic studies of the subtle behavior of microelectronic circuits to their work in engineering standards, the staff of the NBS National Engineering Laboratory (NEL) apply their expertise in engineering and scientific measurement to a broad spectrum of national concerns.

NEL scientists and engineers conduct research in engineering and the applied sciences. They study problems in electronics, automation and manufacturing, chemical engineering, the behavior (and prevention) of fires, and the design and construction of buildings. NEL researchers also provide the nation with state-of-the-art measurement and calibration services in these areas. Their research and services in applied mathematical and computer sciences support technical programs throughout the Bureau.

To provide a more precise voltage reference for maintaining the U.S. legal volt, NBS is exploring the use of superconducting microelectronic circuits. Here, electronics engineer Richard Kautz lowers a prototype into a liquid helium dewar for testing.

For over a century U.S. factories have led the world in production of material goods. From appliances to aircraft, the domestic manufacture of products having discrete parts annually adds $200 billion to the gross national product. This keystone of the U.S. economy, under major challenge from foreign competitors, operates on a system of measurements and standards supported by the NBS Center for Manufacturing Engineering (CME).

Through its measurement services, the Center provides manufacturers with access to the national standards of length, force, and related quantities such as surface texture, acceleration, and acoustical power. The Center's standards activities give industry the technical support it needs to develop voluntary standards for mechanical manufacturing. To extend and improve measurements and the technical basis for standards in these areas, CME conducts research in measurement science, precision engineering, robotics, and software for automated manufacturing systems.

A focal point for the Center's measurement and standards work for the "factory of the future" is the Automated Manufacturing Research Facility (AMRF). Scheduled to be fully operational by the end of 1986, the AMRF is a research form of an advanced flexible manufacturing system made up of robots and machine tools working together under computer control.

A cooperative industry-university-government project, the AMRF has received substantial funding from the U.S. Navy, and $3.5 million in equipment has been loaned or donated by industry. Thirty-eight research associates from industry and researchers from 20 universities work collaboratively with NBS staff on various aspects of the AMRF.

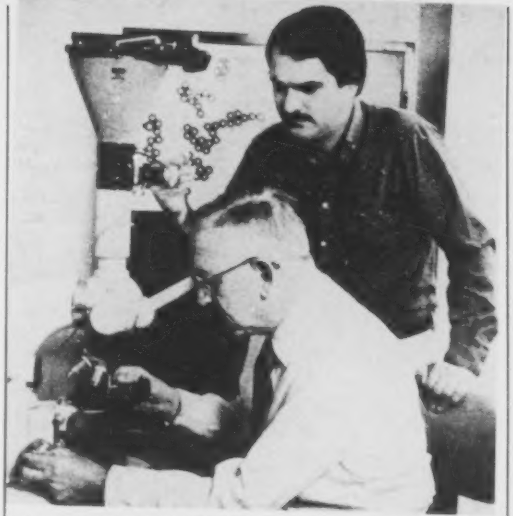
The AMRF consists of a number of work stations, which typically have a numerically controlled machine tool, a robot, and a computer controller. The work stations are organized into cells, which are supplied by a materials handling system and controlled through a computer network. Upon completion, the AMRF will be capable of carrying raw metal material through a series of machining operations to produce a finished, inspected part from a computer design of that part, all under automatic computer control.

In the AMRF, the Center is addressing two critical problems in computer-integrated manufacturing, the basis of the factory of the future. The first problem is to get robots, computers, and machine tools from different manufacturers to communicate and work together in an integrated system. The second is to find a means for carrying out quality control in a fully automated factory environment.

A solution to the first problem is the development of interface standards for the many devices, including the robots, machine tools, sensors, controllers, and computers, which make up an automated factory system. Such standards permit manufacturers of automated equipment to design and build interfaces for their products that protect the proprietary aspects of these products while allowing them to work with those of other manufacturers.

An important example of such an interface standard is the Initial Graphics Exchange Specification (IGES), which was developed by an industry-government coalition led by NBS and adopted by the American National Standards Institute, a private voluntary standards organization. IGES allows the transfer of part-design data between computer-aided design (CAD) systems from different vendors. Every major producer of CAD systems is now using IGES, and organizations such as the U.S. Navy, the National Aeronautics and Space Administration (NASA), and General Motors are writing IGES into procurement specifications.

Within the AMRF, NBS has developed and implemented a hierarchical control system with associated software and database systems as a basis for an entire family of standard interfaces. In such a computer control scheme,



▲ The first space-made product to be offered for sale was NBS Standard Reference Material 1960, 10-micrometer polystyrene spheres that can be used to improve microscopic measurements made in electronics, medicine, and other high-technology areas. Physicists Thomas Lettieri and Arie Hartman (seated) used a technique called "center distance finding" to make very accurate measurements of the spheres.

NBS ROBOT CONTROL SYSTEM
UNIMATE

Research engineers Karl Murphy (foreground) and Rick Norcross study the performance of an experimental parts-deburring station at the NBS Automated Manufacturing Research Facility.

the data processing and computation necessary to accomplish a task is split into discrete levels, with the output of higher levels being used as input commands for lower levels, and lower levels furnishing status reports for higher levels. Each level in the hierarchy accepts tasks from the level above it and splits those tasks into subtasks that are parceled out to the levels below it. Such systems tend to be fast and efficient, because they can be designed so that decisions are made no higher in the architecture than necessary.

Center researchers also are working on a solution to the second problem: how to carry out quality control in a fully automated factory. They are devising the means to automatically monitor and control the manufacturing process so parts are made right the first time. Within the AMRF, researchers have designed and implemented measurement techniques for such process control.

The turning center workstation in the AMRF, for example, employs a microcomputer-based error compensation system for real-time control of the machining process. This system calculates the positioning error associated with a particular location of the cutting tool based on prerecorded data, monitors the temperature of various parts of the machine tool, and, through its automatic tool-setting station, checks the position of the tool's cutting edge relative to the machine's coordinate system. All three elements are used by the system to achieve high-accuracy in part diameters without dependence on post-production inspection.

At the same time that it gives measurement and standards support for industry's development of computer-integrated manufacturing to meet a major foreign challenge, the Center also provides 27 percent of the total volume of NBS calibration services and conducts advanced measurement research in all its areas of responsibility.

For example, Center scientists have developed high-resolution electron and optical techniques for the calibration of the dimensions of industrially important microscopic objects. They are using these techniques to calibrate billions of tiny polystyrene spheres made aboard a NASA space shuttle flight and now being sold as an NBS Standard Reference Material. The spheres, the first product manufactured in space to be offered for sale, will be used to improve microscopic measurements made throughout the economy in electronics, medicine, and other high-technology areas.

In another project, researchers from CME and the Center for Radiation Research have developed a technique for observing simultaneously the magnetic character of a surface and its physical structure over dimensions as small as 100 angstroms. Combining scanning electron microscopy with polarization analysis, the technique can be used to study important magnetic materials such as high-density magnetic media for computers. Collaborative studies with industrial researchers are planned.

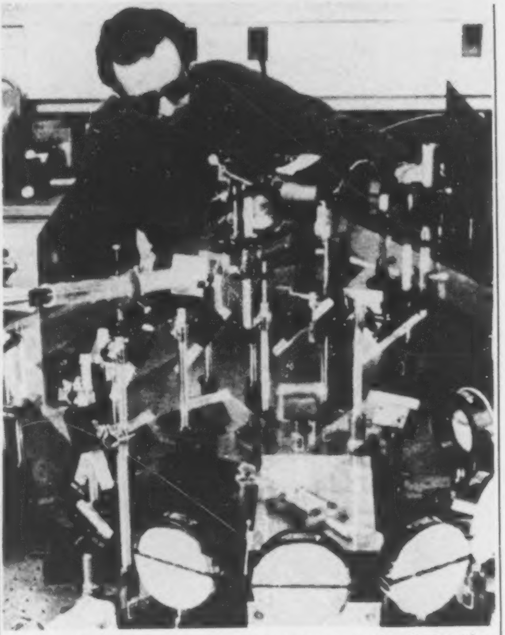
Center for Chemical Engineering

The NBS Center for Chemical Engineering (CCE) provides measurement methods, traceability to national measurement standards, fundamental chemical engineering science, and reliable evaluated data and databases. This work helps to strengthen the competitiveness of U.S. industry in the world market, to assure equity in domestic and international trade, and to provide industry with the engineering basis for improved design and control of chemical processes. Through research programs in chemical process metrology, thermophysical properties of fluids and solids, and chemical engineering science, Center researchers develop experimental and theoretical techniques to provide needed measurements and databases. The results of these efforts include calibration and other measurement services, measurement practices and standards, and engineering data.

The CCE staff work closely with trade associations, steering committees, and consortia of the chemical, petrochemical, plastic, gas, petroleum, and paper industries. Their research also contributes to the science base of the rubber, metals, glass, food, pharmaceutical, and related industries as well as the chemical engineering science programs of other government agencies.

As the prices of natural gas and oil have risen, industry has sought more precise ways to measure these fuels. NBS has developed a unique way to make precise gas flow measurements on a mass flow basis. CCE's mass flow facility in Boulder, Colo., has the capability to test measurement systems with pipelines up to 15 centimeters in diameter. A large heat exchanger is used to vaporize liquid nitrogen for gas flow tests at room temperature and high pressure. The gas is recondensed and weighed as a liquid, providing better than normal accuracy. The Gas Research Institute is sponsoring evaluation of orifice meters using this reference measurement technique. In a companion program supported by the American Petroleum Institute, CCE researchers at NBS in Gaithersburg, Md., are using a water test fluid to improve liquid and gas flow measurements made by orifice meters.

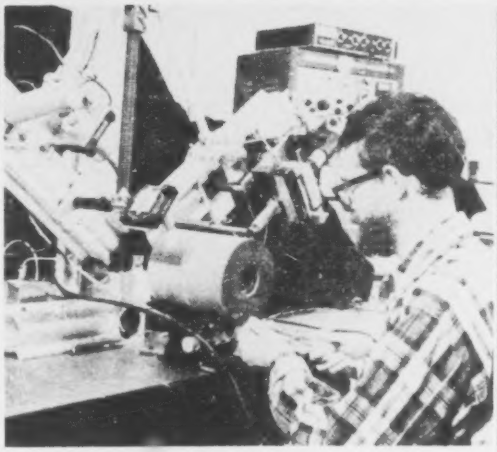
An industry-government consortium of users and manufacturers is sponsoring research at the Center on vortex shedding flowmeters, a device that measures a wide range of flow rates. Researchers are designing computer flow models as well as advanced laser techniques to define the meter flow field. Their work will lead to a fundamental understanding of this type of flowmeter and will give industry the basis for designing and using improved vortex flowmeters.



Laser tomography is used by mechanical engineer Steven Ray to observe high-temperature reactions important in a number of industrial processes such as power and steam generation, recovery of materials, and materials processing.

In response to the long-range needs of the biotechnology industry, the Center has initiated and sponsored workshops in collaboration with Lehigh University on "Process Measurement for Biotechnology" and "Standardization Problems in the Design and Scale Translation of Bioreactors." These workshops complement a small focused program in the Center on bioreactor measurement and bioseparations.

Center researchers are collaborating with an industrial consortium of 13 private firms to develop the properties needed to exploit supercritical extraction separation techniques. They are working to develop the equations-of-state and phase equilibria properties of supercritical



Using an ellipsometer, physicist James Schmidt measures the thickness of extremely thin liquid layers adsorbed or flowing on solid surfaces. The thickness data are then used in the design of more efficient heat exchangers and methods of oil extraction.

fluids (such as carbon dioxide) which can be used as solvents to dissolve large amounts of other fluids (such as crude oil in oil recovery operations). By lowering the pressure of the mixture, the solute can be recovered (separated) and the solvent can be reclaimed to be used again. The use of supercritical fluids may reduce significantly the cost of chemical separations in many future industrial processes.

Improved energy and equipment efficiencies could result from the use of various types of membranes to separate and recover desired products from fluid chemical mixtures. The Center is conducting both theoretical and experimental studies to provide reference data and methods of measuring the performance of different types of membranes. CCE researchers are modeling immobilized liquid membranes, ion exchange membranes, and emulsion liquid membranes to determine the effects of such factors as geometry, time, solubility constants, diffusion coefficients, and forward and reverse reaction rates on mass transfer rates.

To minimize expenditure on high-price fuel, U.S. industry wants to obtain the maximum energy output from fuel combustion. Advanced methods of measuring and evaluating combustion are necessary for this effort to succeed. The Center is pursuing new ways to improve combustion efficiency by studying particle formation and growth at high temperatures. For example, Center researchers are using laser scattering, extinction, and Doppler velocimetry to determine the size of soot particles, their distribution, and their velocity. In soot formation studies, researchers want to know how to adjust the flame, oxygen, and fuel levels to form the optimum amount of soot and then allow the proper amount of time for the soot to burn out. These studies are aimed at improving the performance of boilers, dryers, and furnaces.

The International Association for the Properties of Steam has endorsed steam tables developed by NBS and the National Research Council of Canada. The tables offer an unprecedented range of temperatures and pressures for scientific and general use. The revised steam tables will help scientists and engineers in designing industrial and chemical processes, exploring for petroleum and minerals, designing heat transfer systems, boilers, and turbines, and in harnessing geothermal energy.

CCE researchers correlated all existing quality thermodynamic data on water and steam with a wide-ranging equation of state now known as the Haar-Gallagher-Kell equation, on which the steam tables are based. The equation establishes a formulation that provides scientists and engineers with thermodynamically consistent data on the properties and density of water from the triple point to 2500 °C and from zero pressure of an ideal gas to more than 20 kilobars.

Other important thermophysical properties data are being provided to industry through new correlations, equations, models, and transportable computer programs. These programs predict the viscosity, density, and thermal conductivity of various pure fluids and fluid mixtures. Additional work is in progress to extend the range of these predictive codes to fluid mixtures of over 100 components and to include phase equilibria properties. NBS is making these evaluated properties predictive computer codes available to the public through the NBS Office of Standard Reference Data.

Center for Fire Research

The United States has one of the worst fire loss records in the industrialized world. The NBS Center for Fire Research (CFR) is committed to providing the scientific and engineering bases needed by manufacturers and the fire protection community to reduce both these losses and the cost of fire protection.

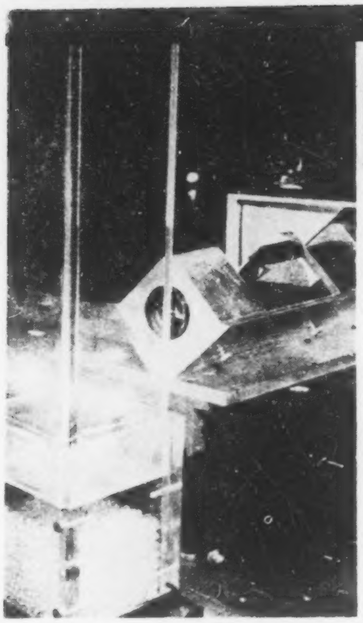
By improving the understanding of the chemistry and physics that take place during combustion and by developing accurate computer models of fire hazards, the Center provides technical information to voluntary standards organizations, engineering and design communities, building industry, fire service and fire protection organizations, and materials manufacturers. The Center also helps these groups to translate the findings into new engineering practices, test methods, and proposals for improved standards or code provisions. NBS, however, does not promulgate or enforce standards or regulations.

One of the most complex and yet crucial phenomena affecting fire growth is soot formation. It is incandescent soot, radiating thermal energy that converts furnishings or construction materials into gaseous fuels, that drives fire growth. Soot also affects people's survivability in fires, both from inhalation and the obstruction of vision. Yet the same particles form the fire "signature" that activates the now-common smoke detectors. Center scientists are conducting a long-term study of the fundamental chemistry and physics of soot formation. They have devised new, laser-based techniques for measuring key molecules in the chemical chain of soot growth. Using multiphoton ionization measurements researchers can detect certain organic species, such as butadiene, throughout the flame itself. They have also obtained profiles of polycyclic aromatic hydrocarbons using ultraviolet and visible fluorescence. Concurrent theoretical calculations on the "stickiness" of aromatic molecules have further clarified which chemistry is significant in building soot particles from small molecules.

Perhaps the topic of most concern in fire research today is that of fire gas toxicity. Most fire deaths are caused by the inhalation of smoke. Carbon monoxide, a combustion product of most burning materials, has been widely considered as the primary cause of these deaths. Recent laboratory tests and analyses of samples from some fire victims, however, have suggested that other toxicants or factors may contribute to some deaths. Building on a decade of leadership in measuring the lethal effects of fire-generated smoke, Center researchers are now studying the extent to which the generation rates of a few principal toxic gases can be used to predict mortality. The results of experiments with carbon monoxide, carbon dioxide, hydrogen cyanide, hydrogen chloride, and reduced oxygen levels are helping to explain the lethality of fire gases.

Center researchers are also creating ways to predict the precise contribution of materials to a fire's severity. Their oxygen consumption technique greatly simplifies the measurement of a burning sample's rate of energy release, a key factor in the rate of fire growth. This method is now used to measure the heat given off by furniture and wall coverings during full-sized room fires. A Center-designed instrument, the cone calorimeter, operates on the same principle and shows exceptional

▲ To study how turbulence mixes fuel gases with air, thereby feeding a fire, research chemist William Pitts designed a unique camera that works with other technologies, including a laser, to help in the research.



promise for predicting the large-scale rate of heat release using small samples

Predicting fire growth requires a fundamental understanding of elemental fire processes such as flame spread and the characterization of fire-induced flows Researchers have developed methods to correlate the speed at which flame spreads across and down a burning vertical surface with the basic thermal properties of the burning materials Measurements of flame height and flame radiation are now providing key information in our understanding of upward flame spread a faster and therefore more critical process

The buoyancy-driven flow of fire gases through doors and open windows and their replacement by ventilated air is also predictable Ventilation and the rate of heat release of the burning materials are the primary factors which determine if and when a room will "flashover," a term used to describe the total fire involvement of all items in a room

Information obtained in experimental work is used in mathematical models designed to predict the vulnerability of a building and its occupants to fire. These computer based models make it possible to simulate real fire situations within a limited budget It is far less costly to "burn" a room or building using a computer Center researchers are now designing a true general purpose model of fire hazard It will include the burning behavior of a room the movement of fire gases throughout a building and the effect of those gases on people By using such a model fire professionals will be able to study "their fire" on a computer varying each component as needed and making quantitative decisions for improving fire safety

Several prediction models are already available In one model, termed ASET (Available Safe Egress Time) the computer code incorporates sound but simplified single-room fire growth It calculates the time at which a smoke detector is activated and the time at which the room becomes uninhabitable The difference between these two events is the time that the occupants of the room have to escape

Another model called FAST (Fire and Smoke Transport Model), can be used to determine the smoke level and temperature in a multiroom building with a fire in one room

The Center recently set up a Fire Simulation Laboratory where scientists and engineers from the fire protection community can see demonstrations and obtain "hands on" experience with various fire models Researchers also use the laboratory to modify models for particular applications

More widespread and proper use of sprinkler systems also could significantly reduce fire losses To assure their efficacy better operational and design criteria are needed The Center has recently produced a computer program for calculating the response time of heat-activated sprinklers It predicts the response time based on characteristics of the fire and the location and thermal properties of the sprinkler heads The predicted temperatures at those sites agree well with steady-state laboratory tests Large-scale tests with growing fires are planned to establish the range of applicability of the computer code

The Center for Fire Research also sponsors a program of grants and to a lesser degree contracts for fire research in support of the internal research program of the Center Approximately 25 grants are awarded to universities and research institutes annually

Physical scientist Randall Lawson adjusts instrumentation on the Bureau's furniture calorimeter, part of an NBS-developed method to measure the rate at which heat is released by burning furnishings. The heat release rate in large part determines how a material will contribute to a room fire.

Center for Building Technology

Over two-thirds of the nation's fixed reproducible wealth is invested in constructed facilities. Moreover, the construction industry is one of the nation's largest, and constructed facilities shelter and support most human activities. The quality of these facilities affects the safety and quality of life of the American people as well as the productivity of U.S. industry.

The NBS Center for Building Technology (CBT) increases the usefulness, safety, and economy of buildings through the advancement of building technology and its application to the improvement of building practices. CBT conducts laboratory, field, and analytical research to develop technologies for the prediction, measurement, and testing of the performance of building materials, components, systems, and practices.

Center researchers concentrate their efforts in computer-integrated construction, structural engineering, earthquake hazard reduction, building physics, building materials, and building equipment. They carry out their work in sophisticated and comprehensive laboratory facilities, which include: a six-degree-of freedom structural testing facility, a large-scale structures testing facility, environmental chambers, a guarded hot plate, a calibrated hot box, a five-story plumbing tower, and anechoic and reverberation chambers.

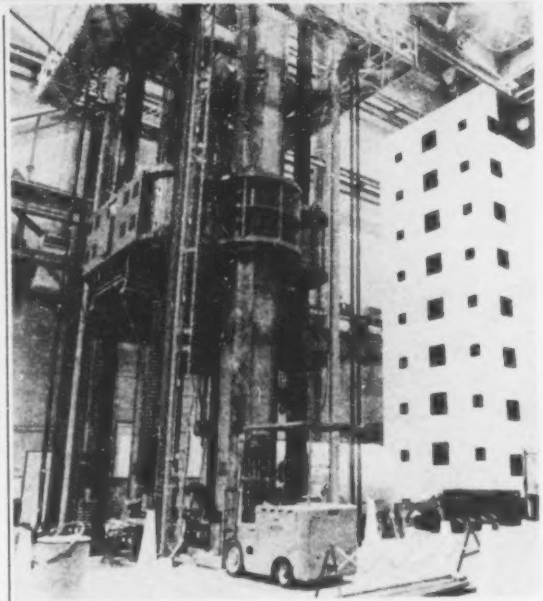
CBT provides technical support and information to a number of voluntary standards groups such as ASTM; the American Concrete Institute; the American Society of Heating, Refrigerating and Air Conditioning Engineers; the American Society of Civil Engineers; and building code organizations. While it contributes to the development of voluntary product standards, the Center does not promulgate or enforce standards or regulations. Through this work, the Center helps eliminate technological market barriers of the construction industry and reduces the burdens of unnecessary or ineffective building regulations while maintaining safety.

CBT represents the United States in several international building research and standards organizations including the International Council for Building Research, Studies and Documentation; the International Union of Testing and Research Laboratories for Materials and Structures; and the U.S.-Japan Panel on Wind and Seismic Effects. These efforts contribute to U.S. use of foreign research accomplishments and the international competitiveness of U.S. building technology.

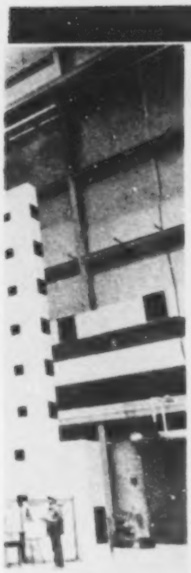
Much of the Center's research is done in cooperation with, or for, other federal agencies such as the Department of Energy, the General Services Administration, the Federal Emergency Management Agency, the Occupational Safety and Health Administration, and the White House. In addition, each year about 70 researchers from international and U.S. universities and industries join CBT staffers in cooperative programs.

As an impartial third party, the Center is called upon to investigate the physical causes of major building and construction failures, such as the walkway collapse in the Kansas City Hyatt Regency in 1981 and the East Chicago, Indiana, ramp collapse in 1982. The results of the Center's investigations are promptly and publicly reported to help preclude recurrences.

More of the Center's research, however, is aimed at developing improved building practices so that such tragedies do not occur. For example, Center engineers are working on ways to determine when poured concrete is strong enough for construction formwork to be removed. They have developed a standardized test for determining



▲ **This computerized, large-scale structural test facility is being used by NBS researchers to test how full-scale bridge and building components perform during earthquakes.**



concrete strength and a computerized method of analysis, both of which are being considered by ASTM for adoption as voluntary standards. Important from both safety and economic standpoints, these tools will help a builder remove the formwork as soon as possible, without risking the workers' safety.

Center researchers have designed and constructed a computerized facility to test how full-scale bridge and building components will perform during earthquakes. In a project sponsored by the National Science Foundation, the Federal Highway Administration, and the California Department of Transportation, CBT researchers are testing 30-foot-high bridge columns under conditions simulating earthquake forces. They are also running tests on columns one-third and one-sixth that size. By comparing the results of both tests, the researchers will be able to determine whether the behavior of small-scale bridge columns can be used to predict that of full-scale columns. They will use this information to evaluate and refine computer models that predict how structures perform during earthquakes, enabling the building community to design safer buildings and bridges with fewer expensive physical tests.

Civil engineer Nicholas J. Carino and co-op student Mary Sansalone from Cornell University are studying a technique known as pulse-echo detection to determine whether it can be used reliably to detect flaws in concrete structures such as buildings or bridge columns.

To help the construction industry respond effectively to the opportunities and challenges offered by advanced computation and automation, CBT is investigating their application to performance prediction and measurement technology. For example, increases in computer power and reductions in computing costs will lead to "smart buildings" with integrated, automated control systems for greater usefulness, safety, and economy in operation. Center researchers are developing and verifying minute-by-minute simulations of the performance of building control systems to help owners, designers, manufacturers, and contractors set up economical and reliable automated control systems for buildings.

Computer technologies will make possible measurement advances in building diagnostics, quality assurance, and prediction of building behavior. CBT is, for example, developing modeling techniques for the microstructure of cements that will allow prediction of how cement ingredients, mixing, placement, and curing will affect the strength and durability of concrete structures.

Center researchers are formulating three-dimensional dynamic computer simulations that will predict heat, air, moisture, and pollutant movements in buildings. These techniques will help improve energy conservation, use of solar energy and natural ventilation, smoke control for fire safety, and indoor air quality.

Other computer simulations are being developed and verified for dynamic tests of the thermal performance of walls. Improved test methods will provide more accurate assessments of effects of wall mass, air and moisture movements, and multi-dimensional heat, air, and moisture flow at junctions of building elements on thermal comfort and energy efficiency.

To provide the technical bases for substantial increases in the efficiency of innovative heat pumps and air conditioners, Center researchers are developing and verifying computer simulations of heat transfer properties of mixed refrigerants and refrigeration cycles.

Center researchers are also working with leading construction standards organizations to adapt artificial intelligence technologies to the needs of the building community and to supply the advanced performance prediction and measurement technologies that will be needed to realize the potential of expert systems for construction.

In virtually all the Bureau's research programs, and in laboratories throughout the United States, there is a substantial need for advanced mathematical, statistical, modeling, and computing techniques. It is the role of the NBS Center for Applied Mathematics (CAM) to provide the best available tools of modern applied mathematics and computing to the NBS staff. Such tools, developed at NBS, are often used widely by American and foreign researchers.

While schooled in theory, NBS mathematicians have their feet firmly planted on the ground of application. They are concerned primarily with developing and adapting mathematical techniques for NBS research programs. Their work takes them into the areas of space science, robotics, fire research, economics, manufacturing, measurement, and development of new hardware and software for future computers. Center researchers are aided in their work by visiting scientists from industry, government, and universities.

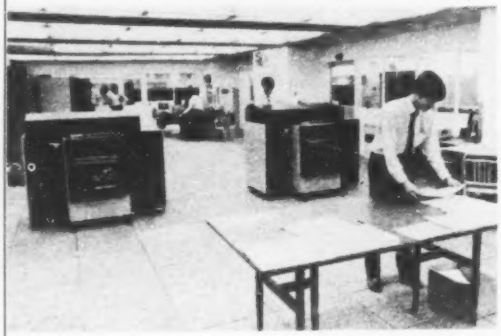
In providing its support service, the Center's professional staff interacts and collaborates with the NBS scientific staff to solve a wide variety of scientific and engineering problems. This work calls for research into computing methods and for computer-intensive studies in the applied mathematical sciences. Current applications involve all aspects of modern scientific computing, including advanced programming languages, knowledge-based systems, interactive software tools, color graphics, and supercomputer algorithms.

The Center also operates the central computing facility—a CDC Cyber 205 supercomputer with a Cyber 855 "front end"—which serves both the NBS Gaithersburg and Boulder sites as well as the National Oceanic and Atmospheric Administration's Environmental Research Laboratories and the National Telecommunications and Information Administration. In addition to managing the central facility, Center staff run local area networks in Gaithersburg and Boulder and provide engineering and software support for distributed computing.

One recently completed project helps fire researchers understand how indoor fires behave. CAM, in collaboration with the Center for Fire Research, developed, tested, and validated a mathematical model of fluid motion and smoke evolution patterns for an indoor fire. Researchers tested calculations based on both two- and three-dimensional models.

The high-resolution dynamic graphics display system used in this project allows researchers to observe the swirling motion of heated air on a computer screen. The system, also permits users to cycle rapidly through any sequence of graphic figures stored in the computer, moving them around in almost any way and observing them from many angles. As the pictures appear to rotate three-dimensionally on the computer screen, new patterns can be perceived. The researcher can "zoom in" to study details or "zoom away" to take in the larger view.

Soon after its introduction, the Center's graphics display system became popular throughout NBS, providing new ways to study a variety of phenomena. The Institute for Materials Science and Engineering used it to develop dynamic displays of polymer chains and molecular structures. The Center for Chemical Engineering used it to simulate molecular behavior in a dense liquid, taking into account local interactions between very large numbers of atoms in order to achieve realistic answers.



> A supercomputer facility has been installed at NBS to meet its large-scale scientific computing needs as well as those of the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration and the Institute of Telecommunication Sciences of the National Telecommunications and Information Administration.

Mathematician James Blue (standing), CAM, and senior research scientist Charles Wilson, CEEE, developed a new computer model, CS 1, which brings sophisticated mathematical analysis techniques to a semiconductor model efficient enough to run on a minicomputer.

The need for a highly sophisticated "three-dimensional" dynamic computer graphics display is also present in the Bureau's robotics research. In order for robot-like machines to operate in an automated manufacturing facility, their grippers must be able to move through space without colliding. CAM is working with the Bureau's Center for Manufacturing Engineering to develop algorithms and software which will plan trajectories for moving objects in space. They are constructing efficient methods for determining paths through regions, avoiding obstructions.

The Center has also developed models which aid in a different area of manufacturing, the development of complex, custom integrated circuits for advanced computers and other electronics systems. This highly competitive field depends on efficient computer-aided design tools. Cooperating with the Center for Electronics and Electrical Engineering, CAM mathematicians are designing a family of specialized computer packages which can be run on minicomputers. The CS-1 package offers features that were previously available only in codes which required large mainframe computers. It has been provided to more than 80 users since 1982.

Applied mathematics also makes an important contribution to the quality and validity of the Bureau's measurement services. Specifically, CAM statisticians blend their theoretical statistical research with extensive experience to aid in the design of measurement assurance programs and in the development and certification of Standard Reference Materials.

Measurement assurance programs provide a framework for industrial and other government laboratories to compare their measurement system to national standards and, thus, improve quality control. Working with the Office of Measurement Services, Center statisticians develop specific measurement sequences and control procedures. They have, for example, helped implement four pilot measurement assurance programs at the Ford Motor Company Central Research Laboratory.

In the case of Standard Reference Materials, which are homogeneous, stable materials that have one or more physical and/or chemical properties accurately measured and certified by NBS, Center researchers plan investigations of homogeneity of the materials and evaluate variability from different sources. In current work, they are investigating improved methods for using Standard Reference Materials to enhance the precision of measurements in the laboratory.

In other recent work, the Center has:

Streamlined the dissemination of alloy phase stability data to industrial users through development of an interactive computer program that generates camera-ready diagrams.

Designed a model that helps state and local governments to evaluate the costs of proposed waste recovery facilities.

Developed and distributed a graphics and statistics interactive language system called DATAPLOT, now used at more than 100 sites including major industrial firms.

Helped develop a model that improves control of a manufacturing method known as unidirectional solidification, used in the production of high quality metal alloys and semiconductors.

Center for Electronics and Electrical Engineering

The scope of research in the NBS Center for Electronics and Electrical Engineering (CEEE) extends quite literally from the sand to the stars. Grains of sand are the genesis of silicon-based integrated circuits, the "miracle chips" of the computer industry and one major focus of CEEE's work. Distant stars emitting radio signals are used by Center scientists to evaluate advanced telecommunications satellite equipment, a second emphasis of the Center's research.

In these areas, and others, Center researchers are working to eliminate measurement-related barriers to the effective use of electrotechnology in a wide range of applications that are important to industrial productivity, national defense, safety, energy, and commerce. To fulfill this goal, they conduct research, develop measurement methods and physical standards, provide calibration and special test services, and develop models and data.

The Center's research is concentrated in four major areas:

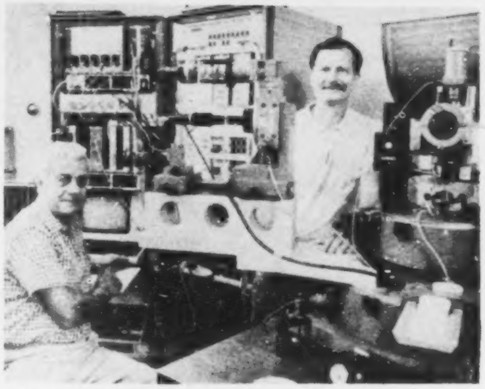
☐ Measurements and analyses for advanced integrated circuits and for semiconductor materials, processes, and devices.

☐ Fundamental metrology for fast signal acquisition, processing, and transmission, covering the analog and digital techniques and frequencies from direct current through microwave to lightwave.

☐ Improved techniques for measuring electric power and energy, fast high-energy transients, and the quality of electrical insulation.

☐ Methods for measuring and characterizing the electromagnetic environment, sources and reflectors of electromagnetic energy, and immunity of equipment to outside interference.

Very large scale integration (VLSI), which yields integrated circuits with hundreds of thousands of transistors on a single "chip" of silicon, is revolutionizing signal processing, communications, and computing. Before the full potential of VSLI can be realized, however, engineers must overcome significant technical barriers related to materials purity, demanding fabrication technology, and circuit complexity. To address these barriers, CEEE is developing measurements, analytical techniques, and Standard Reference Materials (SRM's) for evaluating the quality of semiconductor materials and the performance of integrated circuit fabrication equipment, fabrication processes, and circuit elements.



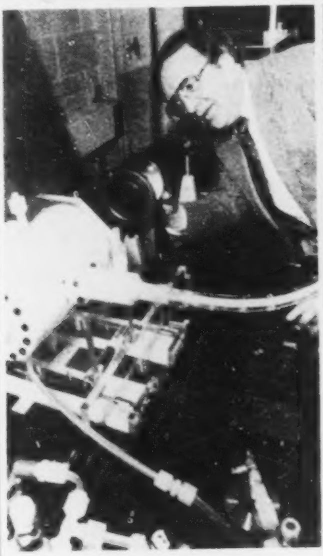
CEEE, for example, has prepared SRM's for calibrating equipment used to measure semiconductor resistivity by the four-probe and spreading resistance techniques. These SRM's help engineers in the semiconductor industry to obtain more accurate measurements of resistivity, one of the most important material parameters in the fabrication of integrated circuits.

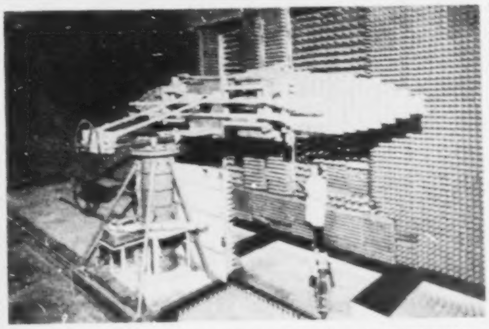
As international trade increases and computer technology spreads throughout the world, the need for international standards becomes critical. NBS has played a key role in bringing together all five of the free-world organizations that write test-method standards for semiconductor materials so these methods can have a common basis in the United States, Europe, and Japan.

Techniques developed by CEEE for measuring linewidths on photomasks have been transferred to virtually every U.S. manufacturer of integrated circuits as well as to manufacturers of photomask equipment. Photomasks, which define the integrated circuit patterns on semiconductor wafers, are key elements in the fabrication of integrated circuits. This work was disseminated to the semiconductor community through a series of training seminars, NBS reports and archival papers, and professional meetings. Future work in this area, which will cover measurements for a broadened range of structures and instruments important to microlithography, will be carried out by the NBS Center for Manufacturing Engineering.

Physical chemist George Candela (left) and physicist Deane Chandler-Horowitz are shown with the computer-controlled principal-angle ellipsometer they designed for measuring the optical properties of thin films on various materials.

Physicist Robert Hebner adjusts a unique NBS device that optically measures electrical fields and space charges in high-voltage insulating systems.





Engineering aide David Dean takes readings of phase shifter settings of the large (4 feet by 25 feet) AWACS antenna being measured in the newly enlarged NBS near-field facility.

Integrated circuit test structures developed by CEEE are widely used by the semiconductor industry and other government agencies. These specially-designed semiconductor devices can be used to characterize integrated circuit fabrication processes, to evaluate the effectiveness of semiconductor processing equipment, to obtain crucial parameters for device and process models, and for product acceptance. Continuing collaborations with several integrated circuit manufacturers are yielding improved test structures and procedures.

To address the metrological needs involved in improving signal acquisition and processing systems, the Center is working on standard waveform generators and measurement systems, some of which use superconducting electronics. To help solve signal transmission problems, CEEE is developing measurements for characterizing optical fibers, national measurement standards for microwave and millimeter-wave parameters, measurement methods for complex antennas, and measurements and standards for lasers.

The Center has taken the lead in providing the technical basis for measurement methods and standards for the rapidly expanding optical fiber communications industry. Measurement methods are tested in round robin intercomparisons organized in collaboration with a committee of the Electronics Industry Association (EIA), refined in the laboratory, and disseminated as EIA or military standards. This work has aided the transition from multimode to single-mode fibers and will continue to help advance the application of optical communications technology.

In the area of microwave and millimeter-wave parameters, CEEE is developing high accuracy six-port measurement systems to support calibration services focusing on critical quantities to 50 GHz. The Center is also working on an automated radiometer that will aid in the calibration of solid state and gas discharge noise sources by extending noise measurements first into the range 1 to 12 GHz and then to 50 GHz. A 94 GHz noise standard of novel design is already in place which will permit extension of noise standards to millimeter-wave frequencies.

Center researchers have developed a new test system for accurately determining the important properties of precision 12-18 bit digital-to-analog (D/A) and analog-to-digital (A/D) converters. Both static linearity and dynamic step response characteristics can be measured and reported in an NBS calibration service now available for these devices.

Using precision waveform synthesis techniques that incorporate microprocessor-based electronics, CEEE

Here electrical engineer Robert Gallawa measures the bandwidth of multimode optical fibers as part of an NBS program to develop measurement methods that can be used in fiber development, fiber evaluation in the marketplace, and fiber compatibility in communications systems.

researchers are working on a new generation of waveform standards. An audio frequency phase-angle standard with 5-20 millidegree accuracy over 2 Hz to 50 kHz now provides special calibration tests for phase-angle meters. New voltage, power, and energy calibrations are being developed based on a dual-channel synthesized waveform source, with 18 bit D/A converters, that generates precision amplitude and phase ac waveforms.

Many Center projects involve direct collaboration with industrial firms and laboratories. For instance, CEEE completed a special study for a major domestic aerospace manufacturer. The company wanted to know if near-field antenna testing could provide accuracies as good as or better than far-field testing for a complete range of measurements. Based on the NBS study results, the company selected the Bureau's near-field antenna measurement methodology for performance testing of antennas to be flown on a new satellite. The indoor near-field technique, pioneered by NBS, offers higher resolution as well as savings in personnel, travel, and equipment costs over the conventional outdoor far-field technique. It is frequently used by industry for performance testing and is now finding use in manufacturing process control for complex antennas.

Some projects involve international collaboration. NBS researchers, working with scientists from a West German standards laboratory, have demonstrated constant voltage steps at 1.2 volts from a series array of 1,464 Josephson junctions operating with a 90-GHz signal. This major achievement showed that there are no scientific barriers to the development of Josephson-junction voltage standards at convenient voltage levels. NBS researchers are proceeding with the development of such a practical, convenient standard.

A recent achievement is a microcomputer based standard for measuring the average power contained in highly distorted electrical waveforms. This standard provides an improved basis for comparing the performance of commercially available wideband wattmeters and permits on site power tests using an NBS standard.

Much of the Center's work in advanced power metrology has been performed in the newly completed high-voltage and high-current laboratories. These laboratories can generate voltage pulses with peak amplitudes up to 600,000 volts and current pulses with peak amplitudes up to 100,000 amperes. They are also equipped with a wide range of conventional, computer-based, and optical systems to measure these pulses and the responses of various systems to pulsed stimuli. These facilities are being used by university and industrial guest scientists in collaboration with Center staff.

The nation's electrical power systems, communications networks, computers, and defense systems are all vulnerable to disturbance by electromagnetic pulses. To resolve system performance problems caused by electromagnetic interference, scientists must be able to measure electromagnetic environmental conditions produced by signal patterns from multiple sources. The Center is focusing on measurements of complex, interfering electromagnetic fields and electromagnetic emissions and on generating standard fields for immunity testing.

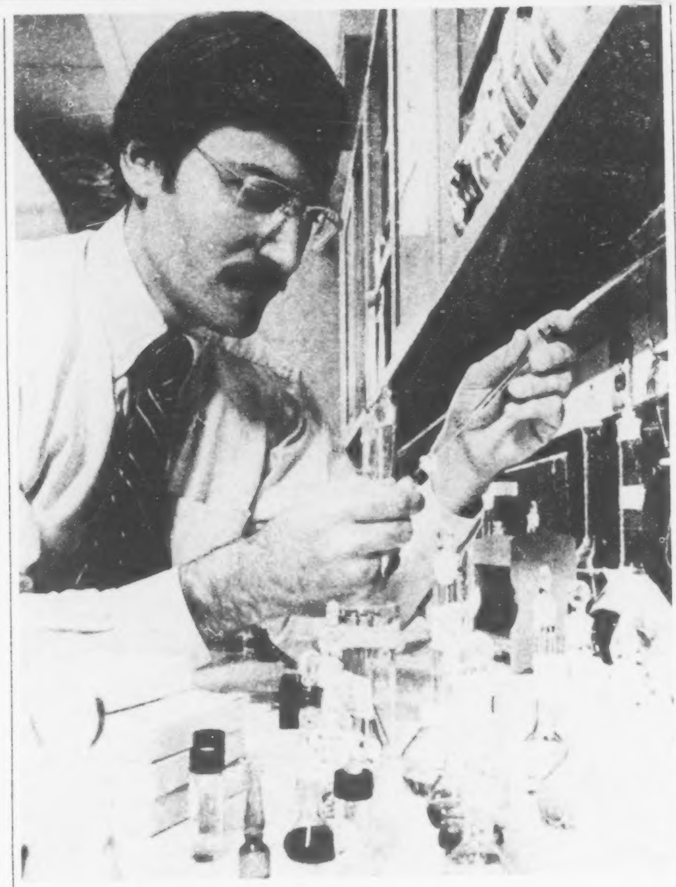
As part of this work, the Center, in collaboration with Sandia National Laboratories, has performed electro-optical measurements of 2.5 million-volt pulses of 100-nanosecond duration. The Center also has developed the capability to characterize voltage sensors in the 1-nanosecond range, a first step toward standardized techniques for evaluating pulse power systems. In addition, the Center has the capability to make the quantitative measurements necessary to evaluate the effects of aging on gaseous insulation.

Research to characterize the electromagnetic environment requires new tools. Broadband sensors (covering from 10 MHz to beyond 10 GHz) and electro-optic transducers in conjunction with fiber optic transmission lines are under development. Center researchers are also working on smaller isotropic sensors needed for measuring fields within small enclosures, such as electronic instrument cases.

All of these projects provide some of the world's most advanced measurement techniques for the rapid development of the electrical and electronics technology which pervades almost every facet of modern life.

National Measurement Laboratory

Our highly technical society demands increasing measurement accuracy for the continued advancement of technology. And improvements in measurement science require an ever deepening understanding of the physical world. Scientists in the NBS National Measurement Laboratory (NML) conduct research at the frontiers of physics which leads to improved realization of the basic physical quantities that underlie measurement science—mass, length, time, temperature, electric current, and radiant intensity. Their research also helps to improve understanding of fundamental atomic, molecular, and nuclear radiation processes. NML provides the nation with state-of-the-art measurement services in thermodynamics, transport properties, chemical kinetics, surface science, molecular spectroscopy, and chemical analysis.



< Research chemist Laurence Hilpert prepares to analyze an environmental sample by gas chromatography/mass spectrometry, a sensitive analytical technique used to measure trace level toxic organic compounds at the parts per billion level.

Center for Basic Standards

As the inheritor of the government's nearly century-old attempts to standardize weights and measures, the NBS Center for Basic Standards (CBS) is responsible for the consistency of physical measurement standards in the United States. It develops and maintains the national standards for mass, length, time and frequency, temperature, pressure, vacuum, and electrical quantities. The Center's work ensures that these national standards are compatible with those of other nations, and the staff provide a variety of measurement services to the public.

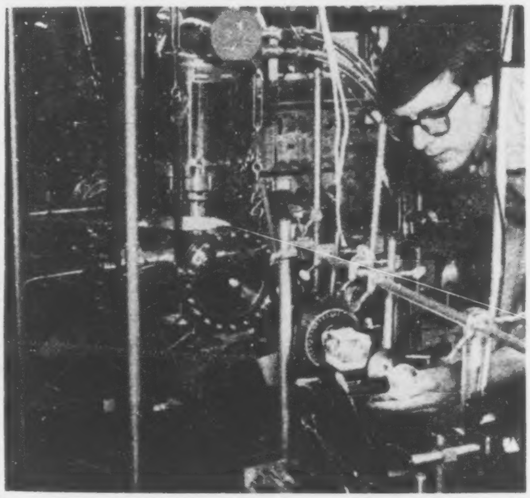
In addition, the Center conducts basic experimental and theoretical research to build a stronger and more accurate foundation for physical measurements and to improve our understanding of the phenomena upon which physical measurements are based. For example, researchers in the Center and their collaborators from the State University of New York at Stony Brook (SUNY) recently announced the first electromagnetic trapping of neutral atoms in experiments at NBS Gaithersburg. To trap the atoms, the NBS/SUNY team developed techniques for producing ultra-cold atoms using laser cooling. With these techniques, an atomic sodium beam is decelerated, stopped, and finally trapped using the radiation pressure from a laser beam. The stopped atoms are then confined in a magnetic trap. Demonstration of a practical method of confining neutral atoms in a trap opens the possibility of a new generation of experiments in atomic physics.

The Center is also working vigorously to develop an "atomic" standard of resistance based on a phenomenon of solid-state physics known as the quantum Hall effect or QHE. This phenomenon occurs in certain semiconductor devices when they are cooled to temperatures near absolute zero and placed in a large magnetic field. Under these conditions, the resistance of the device is quantitized, that is, it has specific, discrete values, and these values depend upon certain invariant fundamental constants of nature. Center researchers have now devised and put into operation a new automated resistance bridge for measuring quantitized Hall resistances with an accuracy of a few parts in 100 million. The QHE has been used to monitor the U.S. legal ohm since the summer of 1983, and it is expected that by 1987 the QHE will be used to define and maintain the U.S. legal ohm.

To assure accuracy of the kilogram, the last remaining artifact standard, the NBS kilograms were compared with those at the International Bureau of Weights and Measures, and they were found to agree to a few parts per billion. A new generation of high-precision kilogram comparators is now being designed and constructed at NBS.

As part of its responsibilities for maintaining and disseminating the nation's physical measurement standards for the benefit of industry, commerce, and science, the Center presents seminars on standards and measurement technology for technicians engaged in industrial metrology. The Center also has published the first volume of a new industrial Measurement Series, called *A Primer for Mass Metrology*.

Through the Joint Institute for Laboratory Astrophysics in Boulder, Colo., which NBS cosponsors with the University of Colorado, Center scientists collaborate with university faculty and visiting scientists to conduct the kind of long-term basic research on which the Bureau's standards, measurements, and data ultimately depend. One recent achievement complementing the atom-trapping experiments in Gaithersburg has been the use of



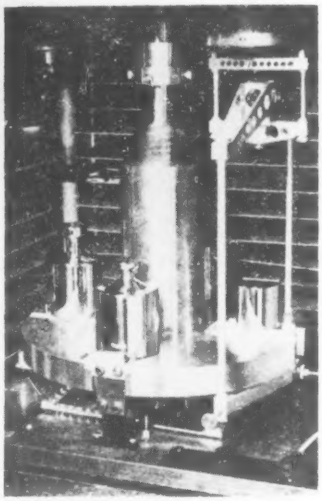
▲ With researchers from the State University of New York, physicists Alan Migdall, John Prodan, and William Phillips, pictured, completed what is believed to be the first successful experiment to trap neutral atoms, an important advance in the technology of atomic physics.

Kilogram Prototype K-20, one of two prototypes that define a kilogram of mass in the United States, and hence the entire U.S. measurement system for mass, is the small platinum-iridium cylinder resting on the balance pan on the right-hand side of this photograph.

radiation from a tunable dye laser to slow, stop, and reverse a free-flying atomic beam of sodium. The major innovation here is the development of efficient electro-optic phase modulators that produce a frequency swept laser sideband to match the changing absorption frequency as the atoms slow down. In addition to potential advances in frequency standards, these experiments should make it possible to test theories in quantum electrodynamics and general relativity.

Center scientists also are exploring the practicality of a space experiment to detect gravitational waves from sources such as binary stars. The experiment involves the use of laser heterodyne techniques to measure variations in the million-kilometer separation of three masses in Earth-like orbits around the Sun.

A new generation of portable absolute gravity meters designed by Center scientists will aid in geodetic, geophysical, geological, tidal, and tectonic studies. The instruments use the free-fall method and consist of four parts: a drag-free dropping chamber, a long-period isolation device, a stabilized laser, and the necessary timing electronics. The meters are sensitive enough to detect vertical tectonic motions as small as 2 centimeters.



In other experiments, Center researchers have demonstrated an ingenious new approach for measuring highly accurate photodissociation quantum yields of electronically excited states. The method uses a fast time-response laser probe to measure the gain immediately after photolysis and the subsequent total absorption, the ratio giving a relative quantum yield that is independent of most experimental parameters. Another researcher has succeeded in measuring the relative abundance of the radicals composed of silicon and hydrogen present in electrical discharges in silane. Such discharges are used in producing solar cells of amorphous silicon, which could be valuable sources of solar-derived energy if the processes involved in the deposition of the silicon compounds were better understood.

In parallel experiments, Center scientists will use an optical fiber thermometer (OFT) and a new NBS photoelectric pyrometer to determine the difference between the thermodynamic temperatures of gold and silver freezing points. The goal of the experiments is to provide state-of-the-art measurements of the various parameters of the OFT so the overall uncertainty of a temperature determination will be less than 20 parts per million.

Because of its high index of refraction and its proximity to the source, the sapphire probe of the OFT captures significantly more signal than the optics of conventional pyrometers. As a consequence, the OFT has greater sensitivity and can operate at lower temperatures than those instruments. In principle, once the OFT is calibrated at a single temperature within its range, it is capable of measuring thermodynamic temperatures over its entire range (600 to 2000 °C).

Using high-energy accelerators and reactors around the world, Center scientists have developed the capability of making very accurate x-ray and gamma-ray wavelength measurements. They have also designed new techniques for investigating the structure of matter and studying high energy interactions that test fundamental theories. Experiments have been carried out at a number of locations including the reactors at the Institute Laue-Langevin in Grenoble, France, and at the Gesellschaft fu Schwerionenforschung in Darmstadt, Germany. Work is planned for a new beam line on the National Synchrotron Light Source at Brookhaven National Laboratory.

Center for Radiation Research

Through its research to understand and measure various forms of radiation, NBS produces information that is used to enhance industrial productivity, assure public health and safety, explore outer space, control pollution, conduct energy research, and design advanced telecommunications equipment.

In the NBS Center for Radiation Research (CRR), scientists examine both electromagnetic radiation, including visible light and x rays, and particle radiation, such as beams of electrons, ions, and neutrons. They study and measure ways in which such radiation interacts with matter, ranging from extended materials surfaces to the molecular and subnuclear levels.

Much of this work results in accurate methods for measuring, characterizing, and producing radiation sources and standards. In recent years, radiation research has developed an important new relationship to health and medicine. For example, doctors are now trying to determine the long-range health effects of human exposure to low-level radiation. To do so, they need new measurement tools and data describing how radiation interacts with the human body.

One research group in CRR is studying the chemical mechanisms through which ionizing radiation affects biological systems. Such information is vital to the proper use of radiation, food irradiation processing, and post-irradiation dosimetry, a technique used to determine if a substance has been irradiated and how much radiation it has received.

CRR scientists have discovered novel physiological antioxidants that may inhibit the effects of radiation or possibly, even promote recovery from radiation damage. Some of their findings, which show how the structure of antioxidants affects their performance, could be used in the design of novel, tailor made antioxidants. These researchers are also exploring the role structure plays in the behavior of DNA-base materials in irradiated cells.

In addition, Center scientists are collaborating with researchers from local universities, the National Cancer Institute, and the Armed Forces Radiation Research Institute to study the DNA-damage/radiation-sensitivity correlations in normal and Alzheimer cells.

▲ By combining an ultrahigh vacuum, high-resolution scanning electron microscope with a new, compact electron spin-polarization detector, physicists (l. to r.) Gary Hembree, CME, Robert Celotta, John Unguris, and Daniel Pierce can observe simultaneously the magnetic character of a surface and its physical structure over dimensions as small as '00 angstroms.

Other research is aiding in the real-time monitoring of radiation used to treat cancer patients where the accuracy with which the dose is administered helps determine treatment success. Special optical waveguide dosimeters with the same response characteristics as human tissue are being developed at CRR to improve clinical dosimetry and thereby help reduce the dangerous side effects of radiotherapy. These dosimeters are small enough to be placed directly into the body through conventional catheters.

The radiation-processing industry is growing by about 30 percent annually, in part because the use of several chemical decontaminants, recently found to be unsafe, is now limited by federal regulatory agencies. Ionizing radiation, for example, could be used instead of EDB (ethylene dibromide) to control pests in foodstuffs, as well as to sterilize medical devices instead of EO (ethylene oxide). Radiation-processing industries have installed more than 200 radiation sources to meet the new industrial demand. The Center has contributed to this technology by developing radiation standards and improved industrial quality control systems to monitor radiation doses, so that safely sterilized products are delivered to consumers.

The steady growth of the use of radiation in medical, industrial, and energy applications has created a need for increased assurance of measurement accuracy. A system of secondary laboratories that will provide the supporting services required for measurement quality assurance is being developed in conjunction with interested organizations in the private, state, and federal sectors. These laboratories will meet documented performance criteria and use procedures that achieve a high degree of consistency with the standards maintained by CRR.

To produce radiation for experimental purposes, the Center builds and operates sophisticated accelerators and other radiation sources that it shares with the general scientific community. The largest is the Synchrotron Ultraviolet Radiation Facility (SURF II), which attracts users from a wide range of universities, government laboratories, and private companies.

SURF II is one of a few sources in the world that can provide continuous radiation in the ultraviolet and near x-ray region of the spectrum. The special properties of this radiation enable NBS to use this synchrotron as the only absolute national radiometric standard in the far ultraviolet range of the light spectrum (below 100 nanometers). It is used as a research and calibration tool by numerous visiting scientists and for the study of optical properties of materials, molecular kinetics, ionization dynamics, and other fields of investigation.

In collaboration with the Naval Research Laboratory and the University of Maryland, with support from the National Science Foundation, a high-resolution spectrometer was installed on SURF II to permit research on the dynamics of energy transfer in atoms and molecules with an energy resolution 10 times better than was previously obtainable.

Other ongoing CRR projects will aid a wide variety of theoretical and practical scientific and technological investigations. These projects involve:

Combining scanning electron microscopy with electron polarization analysis to produce high-resolution images of microscopic magnetic domains. Developed in cooperation with the NBS Center for Manufacturing Engineering, this new measurement technique is being used to study submicron magnetic microstructure of advanced magnetic materials. It is expected to have important applications in a number of fields, including the development of high-density magnetic recording media for computers and small, high-efficiency electric motors.

☐ Constructing a race-track microtron (RTM) electron accelerator that will be used in a variety of radiation research programs of interest to NBS, other government agencies, industrial laboratories, and university researchers.

☐ Establishing a new calibration service for beta particle sources and transfer instruments to assist users involved in radiation monitoring in medicine and nuclear power.

☐ Calibrating rocket-, satellite-, and shuttle-borne instruments used to measure far ultraviolet radiations from the Sun and stars.

☐ Developing atomic physics codes needed to identify atomic ions produced by hot plasmas in fusion reactions and other computer codes that describe collisional interactions between ions and plasmas. These codes provide data necessary for modeling fusion plasma behavior.

Physicist Paul Lamperti adjusts an ion-chamber type detector in an x-ray calibration facility (laser beam is used to align the detector). The ion chamber will be used as a "transfer standard" to calibrate x-ray sources and other detectors.

Center for Chemical Physics

Environmental monitoring, fossil fuel combustion, and biotechnology are among the applications of research conducted by the NBS Center for Chemical Physics (CCP). Center researchers develop advanced measurement techniques in surface science, chemical kinetics, thermodynamics, and molecular spectroscopy. Using these techniques, scientists can achieve greater understanding of the molecular foundations of complex physicochemical systems.

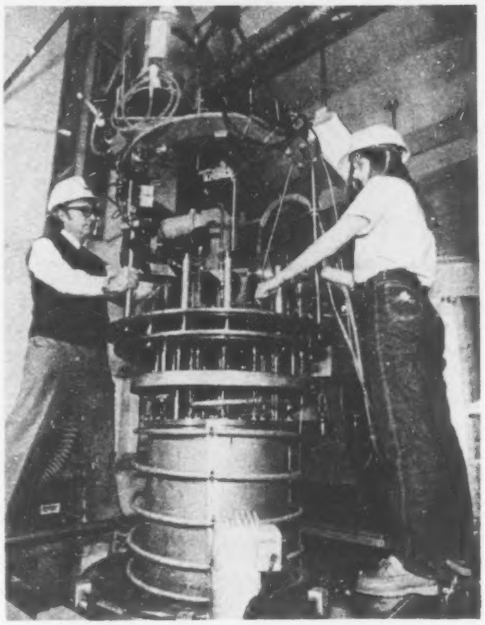
Many rapidly growing areas of technology, including the development of high-performance materials, computers, and semiconductors, involve surface characterization. One thrust of NBS surface science research is to develop measurement techniques for surface characterization. A second major goal of NBS surface science research is to determine the structure and reactivity of molecules adsorbed on surfaces, especially those important in catalysis. To conduct this research, the Center has established some unique experimental facilities.

Center researchers, for example, constructed an atom probe field ion microscope that has several novel features. It combines principles of field ion microscopy—which provides images of a crystal structure's individual atoms at magnifications up to several million times—and a time-of-flight mass spectrometer. The microscope, a powerful tool in materials analysis, can detect the locations and mass of individual atoms in a crystal structure. With it scientists can probe regions ranging from only 5 angstroms in diameter to areas 800 times as wide. Researchers from NBS and industry are now using this microscope to analyze high-technology alloys.

The NBS synchrotron (SURF II) and an x-ray light source at the Brookhaven National Laboratory are being used to study the bonding of atoms and molecules to surfaces of metals and oxides. Combined with other surface-sensitive methods, this research is providing new insights into the geometrical and electronic structures of molecules on surfaces and the electronic properties of the substrate. The results of this research could help to improve materials used in electronics and other high-technology industries.

The study of chemical kinetics at NBS has numerous near-term applications, particularly in controlling and monitoring environmental pollution, of interest to industry, energy, defense, and standards experts. For example, Center researchers have proposed a new way to monitor the effectiveness of the burning of hazardous waste using tracer compounds known to be more difficult to destroy than the hazardous components of the waste mixture.

They have also conducted the first definitive study of the chlorine content of municipal solid waste in the United States. This work provides an important foundation for understanding how chlorinated pollutants, such as dioxins, are formed and destroyed during waste incineration. Sponsored by the Department of Energy, this research is part of a cooperative effort with the Warren Spring Laboratory, United Kingdom, to study waste combustion. In addition, CCP scientists are cooperating



▲ Physical chemist Eugene Domalski and engineering technician Sally Bruce assemble the NBS 2.5-kilogram combustion flow calorimeter for an experiment to measure the heating value of a refuse-derived fuel.

with the Solar Energy Research Institute to provide evaluated thermodynamic data for major components of solid waste.

Industry is interested in the Center's recently patented idea that could help solve the nation's acid rain problem. Center scientists proposed a new chemical process for removing the noxious pollutant sulfur dioxide from industrial gas streams, which could prove more efficient and reliable than the slurry systems presently in use. Other Center scientists are compiling and evaluating thermodynamic data for flue gas cleanup using current fossil fuel technology.

The nationwide effort to develop more efficient and less polluting combustion systems has created a growing need for chemical kinetics data and models. NBS is working to provide the scientific database for the design, modeling, and optimization of high-temperature processes. With the Department of Energy, NBS is asking research groups throughout the United States to cooperate in preparing an evaluated chemical kinetics database of elementary single-step reactions for use in combustion modeling.

As part of its data evaluation services, the Center, in conjunction with the Standard Reference Data Program, produced a new set of tables of chemical thermodynamic properties. More than 60 000 references were used to compile the original data, which were then carefully evaluated and checked for thermodynamic consistency using specially developed computer programs. The tables have been published by the American Chemical Society and the American Physical Society.

In the NBS tradition of providing the measurement base for new and growing industries, the Center is beginning studies in the area of biothermodynamics. CCP researchers are evaluating existing thermodynamic data to estimate the properties of important biological building blocks. They are examining enzyme-catalyzed reactions to obtain data on product formation under varying process conditions and measuring the energetics of nucleic acids by combustion bomb calorimetry. NBS-designed microcalorimeters and a high-performance liquid chromatography technique developed and validated at NBS are being used to investigate the thermodynamics of isomerization reactions.

In a related area, CCP and the National Foundation for Cancer Research have established a cooperative research program to study the chemical behavior of metalloenzymes. These proteins are important in DNA replication and may play a role in the growth of tumors. NBS researchers have developed quantum chemical computation techniques to calculate how complex systems of organic molecules interact with metal ions. These calculations will enable them to predict important chemical properties.

Research chemists Jennifer Colbert and Duane Kirklin prepare Standard Reference Materials using this precision calorimeter which measures the thermodynamic properties of foods, biological materials, and fuels.

Another major effort in the Center is a study of the properties of weakly bonded molecules. Center scientists are presently interested in hydrogen bonding at the molecular level in condensed phase systems. They are coupling theoretical spectroscopy with their infrared and microwave experimental results to explain the highly resolved rotation-vibration spectrum of hydrogen-bonded molecules. From this spectroscopic data, scientists can obtain bond strengths and potential energies of the hydrogen-bonded systems.

In support of the National Aeronautics and Space Administration's project HALOE, Center scientists are making very precise spectroscopic measurements of hydrogen fluoride and hydrogen chloride. This work is aimed at broadening the database used to make and evaluate spectroscopic measurements of atmospheric constituents by ground-based and balloon- and satellite-borne instruments. They are also collaborating with the Chemical Manufacturers Association to develop the spectroscopy needed for the direct detection of trace components of the stratosphere. Most recently, they studied the compound hypochlorus acid, thought to be important in ozone destruction.

Center for Analytical Chemistry

More than 50 billion chemical analyses are performed each year in the United States by scientists and technicians in government, industry, academia, and private and public testing laboratories. The NBS Center for Analytical Chemistry (CAC) helps to ensure the accuracy of these analyses. The Center serves as the nation's reference laboratory for chemical compositional measurements of inorganic, organic, gaseous, and particulate materials.

To help solve national problems that involve analytical chemistry, the Center develops accurate measurement methods and Standard Reference Materials (SRM's) by: (1) investigating fundamental chemical and physical principles to develop new analytical procedures; (2) developing analytical methods, which have been investigated exhaustively to remove bias and obtain high measurement accuracy and precision; (3) extending and modifying existing analytical methods to include new sample types and to permit accurate measurement of samples with lower concentrations of important chemical constituents; and (4) performing standardization research, including certification of chemical compositions in SRM's.

Much of the Center's research has important applications in technology development. For example, to design new high-technology machines and instruments, engineers must be able to predict the performance of materials such as alloys, composites, and electronic components. The performance of these materials is linked to their chemical composition and structure on a micrometer scale. In collaboration with more than 15 guest workers and research associates from the aerospace, metals, and electronics industries, academia, and other national laboratories, Center scientists are using beams of neutrons and ions to measure elemental compositions in materials important in high-technology industries. The data from these techniques—neutron depth profiling and microprobe analysis—are combined using digital image processing to form compositional maps. These maps, with resolution at the tens to hundreds of nanometer levels, can play a major role in establishing relationships between the chemical composition of materials and their performance.

In the biotechnology area, the Center's work has two focuses: to develop measurement methods and standards for use in separating, identifying, and measuring biomolecules and to use the very specialized reaction properties of biomolecules themselves as measurement tools. This research will give scientists in the public and private sectors the means to determine the purity of molecules, such as insulin, produced by bioengineering and to monitor processes in bioreactors. The research can also be used in such unique applications as identifying subspecies of commercially important fish and other marine organisms by protein profiles and determining the effects of various pollutants on the genetic make up of species in the food chain.

While developing new chemical measurement methods and techniques at the cutting edge of technology, Center researchers also produce highly accurate methods that are the cornerstone of quantitative analytical chemistry. Using these methods, Center scientists determine chemical concentrations for a wide variety of complex sample types and have certified the chemical composition of more than 700 SRM's. These SRM's cover a broad spectrum of inorganic and/or organic constituents in a variety of matrices, including human serum, metals, gases, nuclear materials, and

Technician James Norris adjusts the Bureau's ozone reference photometer which is used as a "definitive" standard for calibrating the reference photometers in Environmental Protection Agency regional laboratories.

glasses. Scientists in both the public and private sectors use SRM's to assess the accuracy of their own analytical methods.

In one specific area of research, Center scientists use very accurate mass spectrometry to determine isotopic ratios. They have, for example, recently redetermined the atomic weights of gallium and silver. An accurate value for the atomic weight of gallium is important in the semiconductor industry while an accurate value for silver is needed to determine fundamental physical constants such as the faraday.

The International Ozone Commission has recommended to the World Meteorological Organization that CAC ozone cross-section data be accepted as the international standard. These cross sections, important in determining accurate concentrations of ozone in the atmosphere and stratosphere, are used in the modeling of ozone atmospheric processes and have already significantly reduced previously reported discrepancies between aerial- (plane and satellite) and ground-based ozone measurements.

Using a secondary ion mass spectrometry instrument, metallurgist Dale Newbury is able to map the distribution of elements both on and below a sample's surface.

Center scientists are also developing measurement methods and reference materials for selected vitamins and trace elements in foods and body fluids as part of a major National Cancer Institute epidemiological study to assess the effect of nutrition in cancer prevention.

To provide the more accurate and highly complex measurements that are needed today, Center researchers have investigated the interaction between chromatographic column materials and the chemicals being analyzed. Using the results of this investigation, they will be able to develop chromatographic systems tailored for the separation and analysis of specific organic compounds in complex samples containing thousands of chemicals.

In other work done to respond to new requirements arising from health and environmental concerns, Center scientists analyzed the reactive gases nitric oxide, nitrogen dioxide, and nitric acid using infrared diode lasers to resolve discrepancies in measurements. They analyzed cholestrol and other constituents in human serum for proficiency testing in collaboration with the College of American Pathologists, and developed a diesel particulate SRM and a nitro-polynuclear aromatic hydrocarbon reference material with the Coordinating Research Council. In addition, they produced trace organic reference materials for analysis of toxic polychlorinated biphenyls (PCB's) and dioxins and, in cooperation with industry and the Food and Drug Administration, developed microspectrofluorimetric standards for use in medical research.

The Center, in cooperation with the Environmental Protection Agency, established a pilot environmental specimen bank that contains well-characterized biological samples for analysis of chemicals present in the environment. These samples can be used in the future to evaluate environmental changes that may occur over time and also to distinguish human-caused changes from natural ones. The project to date has involved developing analytical protocols for sampling, processing, and storing samples, evaluating analytical methods for determining trace elements and organic pollutants in biological samples, establishing baseline data on selected environmental specimens, and evaluating the feasibility of long-term sample storage under various conditions. Several international conferences have resulted from this project, and collaboration has expanded to include the National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, and the Food and Drug Administration as well as the governments of Germany, Japan, Canada, and Sweden.

Office of Measurement Services

Reliable measurements can help avoid costly manufacturing mistakes and ensure more effective use of products and systems. They can provide the basis for sound and economical environmental and safety regulations. Good measurements can also improve health care by ensuring the validity of clinical tests and procedures.

At the heart of the NBS mission are services that ensure the accuracy and compatibility of measurements on a national and international scale. Through these services NBS-developed measurement technology also is disseminated to users around the world. Two such programs are directed by the NBS Office of Measurement Services: the Standard Reference Materials (SRM) Program and the Calibration Services Program.

SRM's, produced by NBS since 1906, are stable, homogeneous materials that have one or more physical and/or chemical properties accurately measured and certified by NBS. They are used throughout the world to calibrate instruments and evaluate test methods used in industrial quality control, medical diagnostics, environmental monitoring, and basic metrology. NBS currently maintains an inventory of about 900 different SRM's, which are described in the *NBS Standard Reference Materials Catalog 1986-87*, NBS Special Publication 260. Each year, NBS sells nearly 40,000 SRM units to over 10,000 customers, including 2,500 foreign customers.

While NBS has been providing basic measurement services such as SRM's for about 80 years, the accelerated pace of technology development has called for new and more accurately certified SRM's. Some of the most recently developed SRM's are used in high-technology applications and advanced materials production. These include SRM's designed for controlling the quality of integrated circuits, for evaluating the performance of automated analytical instrument systems such as mass spectrometers, and for evaluating the performance properties of new materials, such as advanced lubricating oils.

Billions of tiny (10-micrometer) polystyrene spheres made aboard the Space Shuttle Challenger have been certified as SRM 1960, the first product made in space to be offered for sale. This SRM is one of a series of micro-dimensional SRM's designed for calibrating particle-sizing equipment used in such fields as metallurgy, clinical chemistry, environmental monitoring, and food technology, as well as in the production of printing inks, explosive powders, and cement. Developed by Lehigh University and the National Aeronautics and Space Administration, SRM 1960 was certified by NBS, in cooperation with a research associate sponsored by ASTM, using an array-sizing optical microscope technique.

Machinist Frank Mills uses a lathe to chip metal that will be ground, sieved, and blended into a titanium alloy Standard Reference Material, which manufacturers will be able to use to control the quality of their titanium products.

The steel and basic metals industries use more than 250 different reference materials to assure quality production and to calibrate automated measurement systems. The SRM 1200 series of low-alloy steels, prepared to NBS specifications, has been the standard for the low-alloy steel industry for more than a decade. NBS is in the process of replacing this entire series of SRM's by materials that meet state-of-the-art specifications. Other recently developed metal SRM's include: unalloyed titanium, low-carbon and sulfur-silicon steel, cast irons, and nickel steels.

SRM's are used not only in America's basic industries and manufacturing but also in areas important to public health and safety such as environmental monitoring and clinical chemistry. NBS now has over 30 SRM's to support clinical chemistry measurements and over 100 SRM's for use in environmental testing, including a new SRM series for use in the analysis of trace organic pollutants.

The calibration and other physical measurement services provided by NBS are as essential as the SRM services. By calibrating a variety of measurement standards and instruments of industry and other government agencies, these services provide the basis for a complete and consistent national system of physical measurements. NBS offers over 300 different calibration services, which are described in NBS Special Publication 250, *NBS Calibration Services Users Guide 1986-88*. Services include a variety of calibrations and special tests for important parameters including fundamental quantities (mass, length, time, electrical current, and temperature) and derived quantities (such as fluid flow rate, electrical resistance, spectral radiance, and microwave attenuation). NBS performs nearly 7,000 calibrations each year on a variety of instruments and transfer standards submitted by more than 1,500 customers.

In its continuing search to identify new measurement requirements and develop priorities for new services, NBS works very closely with such organizations as the National Conference of Standards Laboratories, the Council on Optical Radiation Measurements, and the Institute for Electronics and Electrical Engineers. These organizations have recently issued several reports aimed at assisting NBS in planning future physical measurement service activities.

When customers properly use instruments calibrated by NBS, they can be reasonably assured of accurate measurements in their laboratories. Inaccuracy can occur, however, if the device is damaged in shipment, or if other factors (such as unskilled operators or environmental conditions) hamper accurate measurements. For customers whose measurements must be of the highest accuracy and traceable to national measurement standards, NBS has developed a limited number of Measurement Assurance Program (MAP) services.

MAP's are multilaboratory testing programs that enable participants to evaluate the performance of their total measurement systems relative to national standards maintained by NBS and to the performance of other participating laboratories. NBS offers MAP services for electrical resistance, dc voltage, platinum resistance thermometers, mass, gage blocks, watt-hour meters, laser power and energy, optical retro-reflectance, and optical transmittance. MAP's have been shown to improve the precision and accuracy of participants' measurement systems substantially. To provide information on how to set up and operate a MAP, NBS has published a two-volume manual designated as NBS Special Publications 676-I and 676-II, *Measurement Assurance Programs*.

To enhance the use of accurate measurements throughout the scientific community, NBS has also developed a series of special measurement assurance seminars and training courses, which are held periodically at different locations throughout the United States. These seminars provide in-depth training in both measurement techniques and statistical evaluation of measurement processes and are intended to assist participants in establishing rigorous quality control programs in their laboratories. Areas covered by these seminars include electrical measurements, precision thermometry, and calibration of piston gages. NBS also offers a very popular seminar in the field of chemical measurements, which covers the use of SRM's in chemical measurement applications.

Here engineering technician Linwood Jenkins calibrates a force-measuring instrument which is in turn used to calibrate equipment that tests the strength of materials.

Office of Standard Reference Data

Scientists and engineers frequently find it difficult to be sure about the reliability of data in technical papers. Yet research and development decisions based on inadequate or outdated technical information often result in the costly overdesign of industrial facilities or failure of products.

Researchers at all levels of industry, government, and academia depend on the evaluated physical and chemical databases developed and distributed by the NBS Office of Standard Reference Data. This program, mandated by the Standard Reference Data Act (Public Law 90-396), coordinates the activities of 23 continuing data centers and 40 other data evaluation projects. Each data center monitors an important scientific area and develops and maintains one or several databases, while the smaller data projects often answer the need for specialized databases in particularly important areas of science and technology. These databases are then made available to the technical community in several formats: published, computer-readable, or on-line.

The Office now distributes 10 major databases in computer-readable format on magnetic tape in its Standard Reference Database Series. In this way, the databases are more accessible to a variety of users and can be updated more easily. These databases have numerous uses, such as identifying chemical unknowns encountered in different environments, predicting chemical reaction equilibria, and designing industrial processes. For example, the Photon and Charged Particle Data Center has just prepared two such databases of accurate cross-section data for the interaction of photons and electrons with matter. These data are needed by many scientists working in energy research, medical physics, space science, radiation sterilization, and materials processing. The first, called Photon Attenuation Coefficients in Materials, contains data pertaining to the interaction of x rays and gamma rays with substances in the energy region 1 keV and 100 GeV. The second, which is known as Electron and Positron Stopping Powers of Materials, consists of stopping powers for electrons in 285 materials and for positrons in 29 materials of dosimetric interest in the energy range 10 keV to 10 GeV.

Physicist Stephen Seltzer works on an evaluated, interactive x-ray attenuation database designed to be used in radiation safety and medical physics.

The other databases presently available on magnetic tape are: NBS/NIH/EPA/MSDC Mass Spectral Database, NBS Chemical Thermodynamics Database, NBS Thermophysical Properties of Hydrocarbon Mixtures Database, NBS Crystal Data Identification File, Thermophysical Properties of Helium, Interactive Fortran Program to Calculate Thermophysical Properties of Six Fluids, Activity and Osmotic Coefficients of Aqueous Electrolyte Solutions, and the NBS Steam Tables.

Some of the Office's recent data evaluation and database development work involves the use of prediction and correlation techniques. These techniques help determine hard-to-measure data and provide internal checks to assure that a particular database is scientifically self-consistent. An example of this effort is the NBS Chemical Thermodynamics Database which contains data on the thermodynamic properties of 15,000 substances, all totally consistent with the laws of thermodynamics.

Researchers in the Fluid Mixtures Data Center are developing techniques which will enable scientists to predict transport properties of pure fluids from thermodynamic and molecular data, to predict properties of mixtures from the properties of pure fluids, and to interpolate and extrapolate data over a range of temperature, pressure, and relative concentrations (in mixtures).

Research chemist Marlene Morris, an NBS research associate with the JCPDS International Centre for Diffraction Data, studies an x-ray powder diffraction pattern that was recorded on a laboratory diffractometer.

With such capabilities, researchers can generate needed thermophysical data on-line for specific multi-component mixtures. It would be impossible to provide such information on all possible mixtures in printed tabular form.

To make the Standard Reference Data program successful, its managers must be aware of data requirements in the U.S. technical community and obtain that community's assistance in the job of providing needed data. For this reason, program managers collaborate with a variety of industrial and professional groups. These cooperative activities provide considerable assistance-in-kind to the program, as well as highly effective routes for dissemination of data.

For example, the National Association of Corrosion Engineers and NBS have established a joint program to provide evaluated corrosion data on alloys and other materials. Corrosion of materials, such as in machinery and bridges, cost the United States an estimated $167 billion in 1985. The new cooperative effort is aimed at reducing these costs through improved utilization of materials and application of good anti-corrosion practices. The Office of Standard Reference Data has established a new Corrosion Data Center within the NBS Institute for Materials Science and Engineering. The data center will provide overall guidance of the technical aspects of the program and will assure reliability of the data evaluations.

The Office of Standard Reference Data also collaborates with the Design Institute for Physical Properties Data (DIPPR), sponsored through the American Institute of Chemical Engineers. DIPPR's purpose is to provide reference data to the chemical industry by a combination of critical data evaluation and experimental measurement. The more than 40 organizations that support DIPPR include companies which manufacture chemicals, design processes and plants, and provide a variety of services to the chemical industry. As a result of this cooperative effort, the Office will disseminate the magnetic tape version of the American Institute of Chemical Engineers DIPPR database.

In addition to new activities, the Office of Standard Reference Data enjoys a number of long-standing cooperative arrangements. One is its 14-year collaboration with the American Chemical Society and the American Institute of Physics to publish the *Journal of Physical and Chemical Reference Data*, the major printed output channel for the National Standard Reference Data System. The journal presents compilations of physical and chemical property data that have been evaluated by scientists knowledgeable in the pertinent field of research.

The American Chemical Society handles promotion and subscriptions as well as a unique service: selling bound offprints of articles. The American Institute of Physics is responsible for composition, printing, and mailing, while NBS provides technical and editorial control. By sponsoring this effort and actively disseminating the results to their membership, these two professional societies demonstrate their recognition of the data's importance.

These database development and cooperative activities are merely representative of the large and comprehensive efforts through which the Office of Standard Reference Data provides up-to-date evaluated scientific information to the technical community.

Institute for Computer Sciences and Technology

One of the most significant technological developments of the past 40 years, computer technology is used to carry out basic manufacturing processes, to manage programs and financial activities, and to provide a broad range of consumer and information services. It has spawned increases in productivity throughout the American economy, contributed to the development of high-technology products and services, and advanced science and engineering research.

The NBS Institute for Computer Sciences and Technology (ICST) plays a vital and unique role in providing the standards, specifications, measurement and test methods, and technical guidance needed by government and industry to make better use of computer technology. ICST services and research contribute to the development of better products, the growth of markets, and productive applications of computer products and services.

Through participation in the development of national and international voluntary standards, ICST supports U.S. industry competitiveness and leadership in computer technology.

To improve the management of information resources, computer scientists (l. to r.) Patricia Konig, Helen Wood, and Alan Goldfine are working on specifications for a federal, ANSI, and international standard for data dictionary software.

Computer technology—a technology of rapid change—results in new products and new applications of computers almost every day. As with all new, changing technologies, however, this also leads to new problems relating to computer use.

The Institute for Computer Sciences and Technology's programs in standards development, technical assistance, and research focus on helping government and industry manage this changing technology to improve productivity and help U.S. industry keep its technical lead in international trade.

To carry out its programs, ICST researchers work cooperatively with a broad spectrum of organizations, such as federal, state, and local governments, industry computer users and manufacturers, research organizations, and voluntary standards groups. In many cases, scientists and engineers from industry come to ICST laboratories to collaborate on joint research projects. Technology and test methods developed in Institute laboratories are transferred to industry and academia as well as other government agencies. Industry depends upon ICST's neutrality and technical expertise to support the development of broad consensus standards and the impartial tests needed to assure that products conform to standards.

Voluntary computer standards continue to be one of the most effective means for managing change. Standards help to bring order to the computer marketplace and to broaden the market for computer products. The complexities of computer systems and their many interfaces between users, programs, data, operating systems, hardware, and communications systems make it difficult to link different components and systems, to exchange information between different automated activities, and to take full advantage of automation.

As a large computer user, the federal government's requirements for standards are similar to other large users. More than $15 billion is spent annually on computer-related activities by federal agencies, and the implications of faulty computer operations, waste, and inefficiency are far reaching. Many organizations have made large investments in small computers for individual applications, while microcomputers and large mainframe computers serve other organizational needs. Yet tying these systems together for true distributed processing is still a technical challenge.

As more users need to integrate existing automated systems, the standards process becomes more complex and distributed. Standards development is segmented by technical issues addressed, by special user community needs, and by organizations developing the standards. To meet the federal government's need for coherent and compatible standards, ICST supports the development of voluntary national and international standards that are cooperatively produced by users and industry and that result in off-the-shelf, compatible hardware and software products.

Investigating ways to make software maintenance less complex and time consuming are computer scientists Wilma Osborne and Roger Martin.

ICST staff members provide technical expertise and leadership to the voluntary standards development process by helping to write technical specifications and providing laboratory results. They work with more than 70 different committees in national and international organizations such as the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), the International Organization for Standardization (ISO), the European Computer Manufacturers Association (ECMA), and the Consultative Committee on International Telegraph and Telephone (CCITT). Increasingly, the focus of the Institute's standards-making activities has been in international organizations because of the global nature of communications and information exchange and the importance of having U.S. technology used in international standards. As a result of its close collaboration with U.S. industry, ICST represents U.S. interests in international standards development.

For several years, the Institute has been conducting workshops for vendors and users to discuss the implementation of the Open Systems Interconnection (OSI) Reference Model. The OSI Reference Model, which was developed by ISO with ICST assistance, provides the framework for the development of a complex system of standards that will enable different manufacturers' equipment to work together in computer networks. ICST

ICST researchers (l. to r.) Richard Linn, Jr., Jeffrey Gura, Daniel Rorrer, Wayne McCoy, and Stephen Nightingale (seated) worked with industry to develop a transport protocol test system, which allows vendors and users to test their computer systems to make sure they conform to networking standards.

is cooperating with ISO, ANSI, and other groups to develop the needed standards and with industry in implementing the standards in commercial products for the office and factory.

Participants in the workshops have represented more than 175 organizations, including computer manufacturers, semiconductor manufacturers, word processing vendors, process control vendors, communications carriers, and industry and government users from the United States, Canada, and Europe. Two successful demonstrations—one at the 1984 National Computer Conference, the other at AUTOFACT '85—of standards for the OSI reference model have resulted from the workshops. Two major U.S. corporations, General Motors and Boeing Computer Services, have adopted standards for their computer operations based on the workshop effort. The corporate standards are Manufacturing Automation Protocol (MAP) and Technical and Office Protocol (TOP), respectively.

ICST contributed to these demonstrations and to the development of commercial products implementing the standards by helping participating organizations test their products using test methods developed in institute laboratories. New techniques were also devised to automate the design-to-implementation, testing, and performance measurement processes, thereby reducing the time needed to write the sophisticated testing procedures. In addition, ICST will coordinate a globally distributed digital data network for OSI research—called OSINET—to which 15 companies have agreed to commit resources.

Institute researchers are also working on the standards needed to integrate different computer programs and user applications and to establish standard formats and definitions for data processed by computer. They have contributed to voluntary standards for programming applications for database and graphics systems as well as for tying these applications languages to high-level programming languages. These standards will make programming easier and programs, training, and skills transportable from one system to another.

ICST's standards efforts cover other application areas including system interfaces and information exchange. For example, institute researchers are involved in developing standards for magnetic media and for structuring data files on media. ICST is supporting more than 35 different final, proposed, and planned standards that represent basic requirements for exchanging information stored on different types of magnetic media.

Developing standards is just the first step toward compatibility of products. The standards must be implemented properly in products to assure compatibility with other products, and test and measurement methods are essential for ensuring that products and systems meet the increasingly complex standards. Without tests, standards are simply paper specifications, and no one can be sure that products are compatible.

Industry is contributing to this effort by providing researchers to collaborate with institute staff members and by donating research equipment. More than 20 major computer and communications companies have been working with ICST in developing test methods for network standards. To extend that effort to the critical software needed for processing data distributed in networks, ICST has started a new project with industry to develop test methods for software standards. These include data base management systems, data dictionary systems, computer graphics, programming languages, user interfaces to operating systems, and office systems/document interchange.

In the case of magnetic media, reference measurement systems and reference materials are needed to support the standards that are developed for tapes, disks, and cartridges. ICST has developed and maintains such reference services for six different types of magnetic media. Standard Reference Materials are used to evaluate the performance of media and systems and to maintain quality control over their production.

NBS and the Physikalisch Technische Bundesanstalt (PTB) in West Germany are the only organizations providing these services. To focus the efforts of both organizations more effectively, NBS has agreed to concentrate on developing new Standard Reference Materials for magnetic tape products while PTB will center its work around the production of reference materials for flexible disk cartridges. ICST is also working on standards and supporting services for optical digital data disks, a new storage technology.

Electronics engineer James Park works on Standard Reference Materials that can be used to evaluate the performance of magnetic storage media.

Institute researchers provide technical assistance to other government agencies and industry in a number of areas, including computer security, communications security, and reduction of software management costs. The need for security has increased as organizations become more dependent on computers. Systems and networks must be protected against all hazards including "hacker break-ins," computer center disasters, computer-related crimes, erroneous funds disbursements, disclosure of sensitive information, and theft of data and software. If left uncorrected, system and network vulnerabilities could result in costly losses and dangerous interruptions to data processing.

ICST researchers are currently investigating security for small computer systems, contingency planning, communications security, and personal identification methods. Other technical efforts involve development of risk assessment methods, use of cryptography, and development of computer-access controls. A number of management guides, tests, performance measures, standards, and guidelines have been developed to assist organizations in protecting their computer information from unauthorized modification, destruction, or disclosure and in assuring that computers are available for processing when needed.

Working with the President's Council on Integrity and Efficiency as well as computer experts and auditors from government and industry, the Institute is developing procedures to help auditors determine the most critical aspects of system security to review.

Protection of electronic funds transfers is important to the stability of the banking system as billions of dollars are transferred electronically each day. ICST researchers are working with the banking community and the Treasury Department to apply data encryption techniques to protect the transfer of financial messages. A Treasury policy requires that electronic funds transfer (EFT) messages be authenticated using federal and voluntary industry standards to assure that messages have been sent by an authorized party and have not been tampered with during transmission. These researchers are also helping the voluntary standards community to develop the standards needed for data authentication and encryption of data.

As part of the same project, ICST researchers have developed tests to validate devices that implement the standards. Vendors can now test their devices via electronic hook up with the Institute. The test results will be used by Treasury to certify devices for use in EFT transmissions. The National Security Agency is also assisting in this effort.

Institute researchers are planning a cooperative program to investigate the possible use of small, credit-card-sized devices for personal identification and record keeping. Meetings with government and industry representatives have pointed up the potential applications of such devices, as well as the security technology that is needed to make them practical and effective.

Several ICST projects support the Office of Management and Budget's government-wide initiatives to reduce the costs of software management and to manage end-user computing. Well-publicized problems with complex systems have focused attention on the critical need for high-quality, error-free software. The Institute is investigating ways to make the process of software maintenance less complex and time consuming.

While the use of off-the-shelf software packages avoids software development costs, these software packages must be compatible with existing software if they are to be integrated into existing systems. Institute researchers are examining approaches for evaluating software packages to assure that they meet user requirements. They then plan to issue guidelines to help federal agencies develop their requirements for off-the-shelf software and to aid in the selection of software packages that meet their needs.

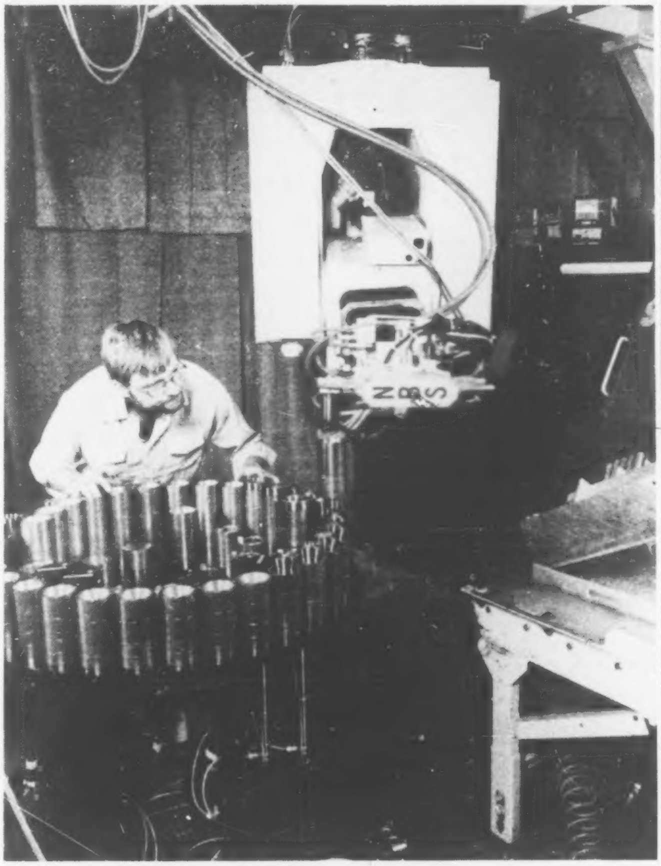
ICST is also studying other ways to improve the productivity of workers who develop their own computer applications, for example, the use of fourth-generation programming languages to make programming methods more efficient and easier to maintain. To make the exchange of information between computer-based office systems more efficient, ICST is developing standards for document interchange between different manufacturers' systems.

In addition to providing general technical support to computer users, ICST carries out specific projects on a reimbursable basis for federal agencies. Typical projects include: assistance in establishing and maintaining software development policies and guidelines, evaluation of the data management capabilities of software, assistance in developing and implementing computer security procedures, and development of prototype network systems to meet special agency requirements.

The results of ICST research are disseminated through guides, forecasts, analyses, workshops, and symposia. ICST publishes a computer science and technology series that transfers technology about new applications to users. The Institute is also experimenting with automated information services that computer users can reach by phone using computer terminals and small computers. In other cases, teleconferences are used to exchange information with state and local governments and industry users. Working directly with industry and computer users to get standards implemented in products is ICST's preferred way of transferring technology. This helps to advance the development of standard products and the productive application of computers.

Special Programs

The planning, organizing, and executing of NBS research programs require extensive interaction with numerous groups to assure that NBS is developing the measurement technology needed by the country and that it is reaching the Bureau's clients. Many of these interactions are coordinated through the Associate Director for International Affairs, responsible for cooperative work with other countries, the Office of Research and Technology Applications, which disseminates the results of NBS research to industry and state and local governments, and the Office of Product Standards Policy, which, among other activities, provides guidance and services to state and local weights and measures officials.



Research associate Eric Reisenauer from Naval Ordnance Station examines a microcomputer-controlled buffer system for robot fingers, turning center collets, and quick-change tooling in the NBS Automated Manufacturing Research Facility.

International Affairs

The laws of science and the art of measurement know no international boundaries. To achieve its goals, NBS must interact with scientists and institutions of other nations whose objectives are related to those of NBS. The Bureau's international activities include:

☐ Representation of the United States in international governmental bodies such as the International Bureau of Weights and Measures, which was created by the Treaty of the Meter, and the International Organization of Legal Metrology.

☐ Participation in bilateral agreements for cooperation in science and technology. NBS currently is participating in cooperative programs with Canada, the United Kingdom, Japan, India, Italy, Korea, China, Yugoslavia, Spain, Egypt, Hungary, Pakistan, and other countries.

☐ Provision of training and technical assistance to developing countries.

☐ Interchange of guest scientists with foreign countries. In 1985, NBS hosted several hundred short-term foreign visitors, plus 265 foreign guest scientists from 40 countries who worked at the Bureau for periods from 2 weeks to 1 year or more. The number of foreign scientists working at the Bureau has increased dramatically in recent years, as has the number of NBS personnel visiting or working at foreign institutions.

United States participation in international standards organizations dates from 1875, when the United States joined other countries in signing the Treaty of the Meter. From the time of the Bureau's birth in 1901, NBS has been assigned the responsibility of representing the U.S. government in technical activities associated with this treaty. The NBS Director serves as the U.S. delegate to the quadrennial General Conference on Weights and Measures and is a member of the International Committee of Weights and Measures, which sets policy and guides the technical work of the General Conference. NBS staff members serve on the eight technical subcommittees of this parent body.

In a similar vein, NBS cooperates with related institutions in the major industrialized countries of the world, including Japan, Germany, the United Kingdom, France, and Canada. An example of this cooperative effort is the U.S.-Japan Panel on Wind and Seismic Effects, for which NBS serves as co-chair for the United States. By sharing research results in an annual joint seminar, and by jointly determining objectives for future research, the two countries are able to work together to minimize future damage by earthquakes, hurricanes, and typhoons.

An example of the Bureau's work with developing countries is its program of providing technical assistance to Egyptian standards organizations. Sponsored and funded by the U.S. Agency for International Development, Egyptian scientists are trained at NBS, and NBS specialists are sent to Egypt to provide consultation and assistance in procuring special equipment.

▲ Literally hundreds of guest workers from other countries visit or work at NBS each year. Shown here is Yang Zu Zhang of the Shanghai Bureau of Metrology, People's Republic of China, who is working with researchers in the Center for Analytical Chemistry.

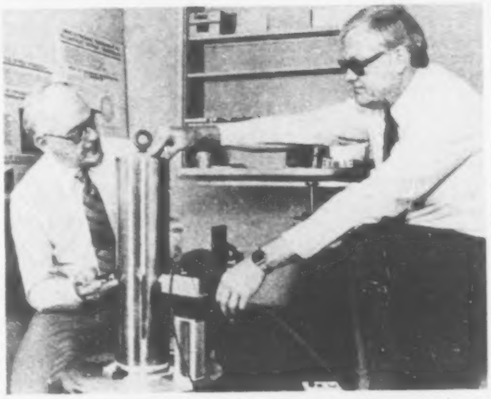
Office of Research and Technology Applications

The competitiveness of U.S. industry and the well-being of U.S. society are increasingly dependent on technology. In 1985 the United States spent $107 billion on research and development. The federal government spent about $50 billion of that amount, with federal laboratories doing approximately $10 billion of the research and development. For the nation to gain the maximum benefit from the federally sponsored research, the results must be actively made available to users and interested members of the public. The Stevenson-Wydler Technology Innovation Act of 1980 promotes the active transfer of federal technology to private industry and state and local governments.

At NBS, the Office of Research and Technology Applications (ORTA), as required by this Act, provides private industry and state and local governments ready access to federal technology and to NBS research and facilities, in particular. ORTA staff respond to inquiries and establish cooperative research programs between NBS and other organizations.

One of the most popular and effective ways to make NBS research and facilities accessible to U.S. industry is through the Industrial Research Associate program, which NBS has run since the 1920's. Under this program, industrial scientists and engineers join NBS researchers in solving technical problems of mutual interest. Industrial interest in collaborative research is at an all-time high: Industry currently sponsors and pays the salaries of about 200 research associates in more than 80 different programs at the Bureau. Recent changes make the program even more attractive to industry. For example, revisions in patent policy give industrial research associates rights to inventions conceived while working at NBS. And, under prescribed circumstances, companies can now conduct proprietary research in NBS facilities.

In keeping with the growing national interest in industry-government interaction, ORTA participates in a wide range of joint activities. The Office arranges and participates in industry-government workshops that promote the exchange of information on exciting advances in technology. The Office also helps state officials organize and implement conferences on opportunities for using federal technology. ORTA staff and other NBS managers joined the Department of Commerce Office of Intergovernmental Affairs and representatives from other Commerce agencies in visits to Louisiana, Oregon, Pennsylvania, and Minnesota to advise the state officials about federal services that might promote their economic development.



▲ In a cooperative industry/government effort to develop process control sensors for the steel industry, NBS metallurgist Floyd A. Mauer (left) and David C. Rogers, American Iron and Steel Institute research associate from U.S. Steel Corporation, set up a cylindrical steel billet for ultrasonic tomographic temperature imaging measurements.

The Office is part of a federal laboratory computer network set up to locate federal technology and facilitate its transfer to potential users. Also, ORTA staff provide leadership for the U.S. Technology Transfer Society.

ORTA participates in the national and regional meetings, panels, and workshops of city, county, and state government officials to help them solve their technical problems. Subjects of particular current interest to these officials are computer security and technology, fire research, building technology, and law enforcement product standards.

Office of Product Standards Policy

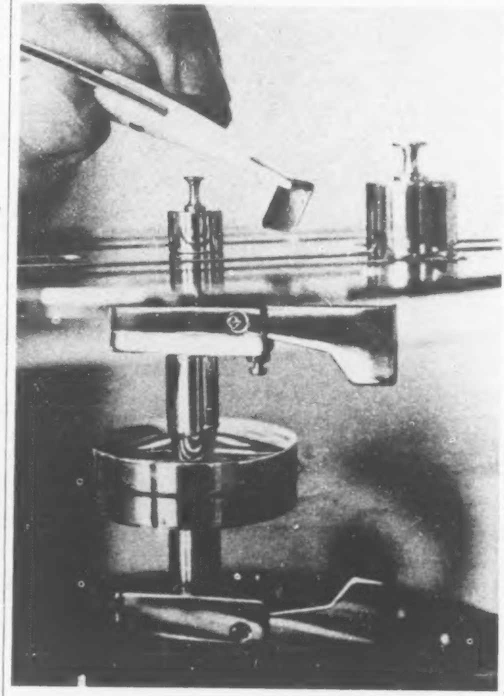
The NBS Office of Product Standards Policy (OPSP) formulates and carries out federal policy relating to national and international standardization, laboratory accreditation, and legal metrology. As part of this effort, the Office works with domestic, foreign, and international organizations concerned with standardization and related measurement activities. The Office also provides guidance and services to state and local weights and measures jurisdictions and manages U.S. international legal metrology obligations.

The Office maintains information on a quarter of a million standards-related documents and responds to thousands of inquiries each year. Its National Center for Standards and Certification Information develops directories and indexes and disseminates information to the public. In support of U.S. trade, the Office serves as the U.S. Inquiry Point for the Agreement on Technical Barriers to Trade ("Standards Code") of the General Agreement on Tariffs and Trade and furnishes technical assistance to industry and trade negotiators in addressing trade problems with other countries.

To promote equity in the marketplace, OPSP sponsors the National Conference on Weights and Measures. Office staff develop procedures to evaluate measuring instruments for the marketplace, coordinate training programs, support state metrology laboratories, and cooperate with the Conference to promote nationwide uniformity of state and local government requirements pertaining to measurements in the marketplace. At the international level the Office manages U.S. participation in over 100 committees of the International Organization of Legal Metrology (OIML), which aims for international uniformity of requirements for legal metrology.

In view of the importance of having valid U.S. test data accepted abroad, the Office works at the national and international levels to assure reliable laboratory testing. OPSP conducts workshops on test methods, develops techniques for proficiency testing, and operates the National Voluntary Laboratory Accreditation Program (NVLAP). NVLAP is a voluntary system for assessing and evaluating testing laboratories and accrediting those found competent to perform specific test methods or types of tests on products and materials. Through this program, laboratories are accredited for testing a variety of products, including telecommunications equipment, thermal insulation, and radiation dosimeters.

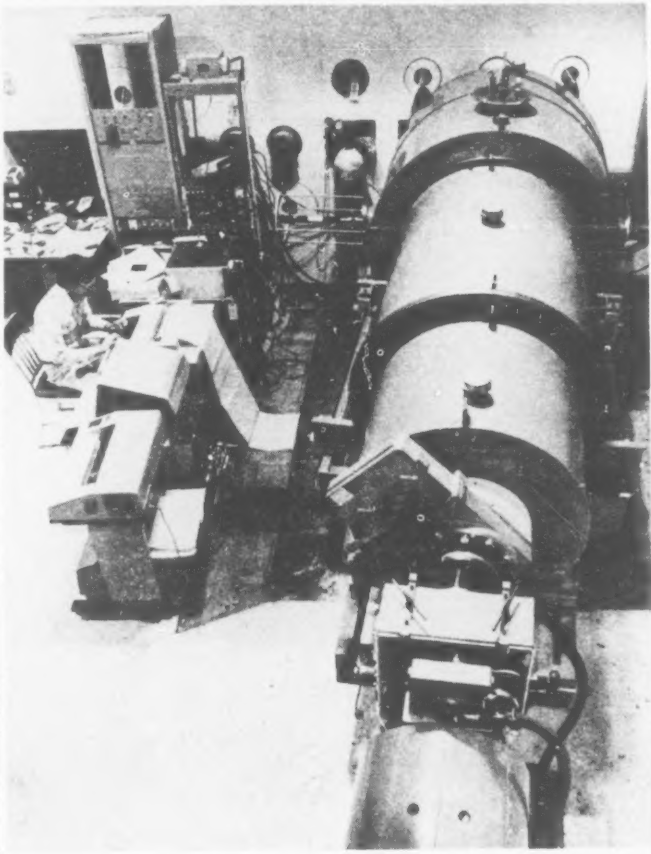
The Office works closely with international organizations to have U.S. technology and practices incorporated in international standards and guidelines. Its staff serve on key committees of the United Nations Economic Commission for Europe, the International Laboratory Accreditation Conference, the International Electrotechnical Commission, the International Organization for Standardization, OIML, and many others.



To provide traceability to national standards, the Office supports the system of state weights and measures laboratories.

The Bureau's work is carried out by highly skilled staff who are often recognized as national or international leaders in their specialties. In Gaithersburg, Maryland, located north of Washington, D.C., NBS has about 2,350 full-time employees working in 26 buildings on 576 acres.

The Bureau also has nearly 390 full-time staffers who work in 14 buildings on 208 acres in Boulder, Colorado. The Joint Institute for Laboratory Astrophysics, co-sponsored by NBS and the University of Colorado, is located in Boulder, where scientists study atomic and molecular physics and astrophysics. At Ft. Collins, Colorado, NBS operates radio stations WWV and WWVB, which broadcast standard time and frequency information. Another station, WWVH, broadcasts from Kauai, Hawaii.



In an overhead view of the small-angle neutron scattering (SANS) spectrometer, physicist Charles Glinka analyzes data at a computerized color-display terminal linked to a two-dimensional neutron detector located inside the 3.5-meter flight path tube behind the sample chamber.

As the nation's central reference laboratory, the Bureau houses a number of special facilities and equipment, many of which are available for use by the scientific and engineering communities—some for conducting proprietary research. For example, the NBS 20-megawatt research reactor is a major national facility for cooperative research in materials characterization. About 200 scientists from industrial firms, universities, and federal agencies use the NBS reactor each year in projects ranging from nuclear theory to analyses of food contaminants.

An electron accelerator, capable of producing well-focused electron beams at energies between 14 and 140 million electron volts, is used to produce high-energy electrons, positrons, photons, and neutrons for nuclear physics research, neutron measurements and standards, analytical chemistry, and dosimetry research. As part of this facility, a 200-million-electron-volt racetrack microtron, which will be a user facility for research in nuclear physics, is now being installed. The microtron, which is scheduled to be available for research in late 1987, is expected to have a number of unique performance characteristics, including a continuous-wave beam, high current, easily variable energy over a wide range, excellent emittance, and very small energy spread.

The Bureau's Synchrotron Ultraviolet Radiation Facility (SURF II) is a 280-million-electron-volt electron storage ring that radiates synchrotron radiation which is highly collimated, nearly linearly polarized, and of calculable intensity. SURF II is used in studies in atomic, molecular, biomolecular, and solid-state physics; surface and materials science; electro-optics; and chemistry and radiation effects on matter.

Among other NBS facilities are an Automated Manufacturing Research Facility, several environmental chambers, a tri-directional structural testing facility, a fire research laboratory which includes a facility for smoke movement studies, a 2-story structural steel test facility, and a network protocol testing and evaluation laboratory. In addition, an extensive instrument shops group answers specialized research needs. Shop capabilities include glass blowing, optics, and metalworking.

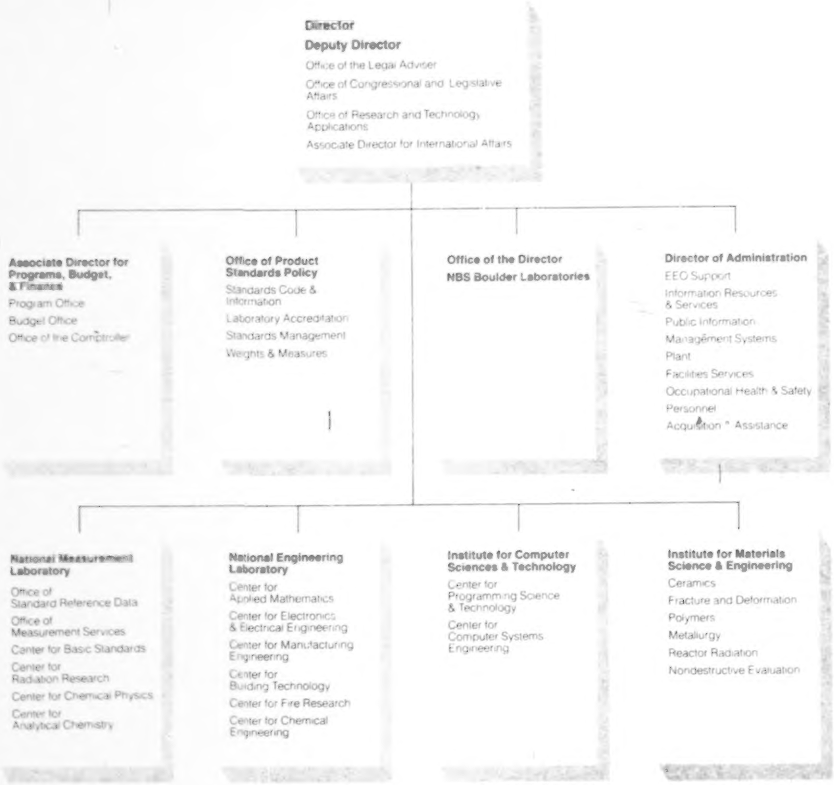
In fiscal year 1985, direct Congressional appropriations accounted for about 60 percent of NBS' budget of $208.9 million. The balance resulted from work performed by NBS for other government agencies, and from the sale of NBS goods and services such as Standard Reference Materials and calibrations.

Total NBS Operating Funds—All Sources

(in millions of dollars)

	FY 1984 (actual)	FY 1985 (actual)	FY 1986 (estimate)
Measurement research and standards	$ 55.8	$ 60.7	$ 61.7
Materials science and engineering	27.5	31.2	33.4
Engineering measurements and standards	72.1	77.9	79.1
Computer sciences and technology	12.4	13.6	13.0
Research support activities	28.9	25.5	26.2
Total NBS	**$196.7**	**$208.9**	**$213.4**

Directory



Director

Deputy Director

- Office of the Legal Adviser
- Office of Congressional and Legislative Affairs
- Office of Research and Technology Applications
- Associate Director for International Affairs

Associate Director for Programs, Budget, & Finance

- Program Office
- Budget Office
- Office of the Comptroller

Office of Product Standards Policy

- Standards Code & Information
- Laboratory Accreditation
- Standards Management
- Weights & Measures

Office of the Director

NBS Boulder Laboratories

Director of Administration

- EEO Support
- Information Resources & Services
- Public Information
- Management Systems
- Plant
- Facilities Services
- Occupational Health & Safety
- Personnel
- Acquisition & Assistance

National Measurement Laboratory

- Office of Standard Reference Data
- Office of Measurement Services
- Center for Basic Standards
- Center for Radiation Research
- Center for Chemical Physics
- Center for Analytical Chemistry

National Engineering Laboratory

- Center for Applied Mathematics
- Center for Electronics & Electrical Engineering
- Center for Manufacturing Engineering
- Center for Building Technology
- Center for Fire Research
- Center for Chemical Engineering

Institute for Computer Sciences & Technology

- Center for Programming Science & Technology
- Center for Computer Systems Engineering

Institute for Materials Science & Engineering

- Ceramics
- Fracture and Deformation
- Polymers
- Metallurgy
- Reactor Radiation
- Nondestructive Evaluation

Technical work is carried out in the National Measurement Laboratory, the National Engineering Laboratory, the Institute for Computer Sciences and Technology, and the Institute for Materials Science and Engineering. These groups are supported by the Office of the Director of Administration; the Office of the Director, NBS/Boulder Laboratories; and the Office of the Associate Director for Programs, Budget, and Finance. This amalgam of people and programs forms a community dedicated to service. An interdisciplinary approach allows NBS to provide the nation with scientific measurements of high precision and accuracy, coupled with solutions for current and future technological problems.

This brochure highlights only some of the Bureau's programs. For more information on specific projects, contact the people listed in this directory. To reach members of the Gaithersburg, MD staff, dial (301) 921 + extension or write to the National Bureau of Standards, Gaithersburg, MD 20899. Bureau staff located in Boulder, CO, can be contacted on (303) 497 + extension or write to the National Bureau of Standards, Boulder, CO 80303. Boulder staff members are designated in the directory with asterisks.

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Mrs. E.C. Cassidy, Director (2441)

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Industrial Liaison/Research Associates
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State and Local Governments Liaison
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Associate Director for International Affairs
Dr. E.L. Brady (3641)

Office of Product Standards Policy
Dr. S.I. Warshaw, Director (3751)
Mr. J.L. Donaldson, Deputy Director (3751)

Office of the Director, NBS/Boulder Laboratories

The Office of the Director, NBS/Boulder Laboratories, which is located in Boulder, Colo., oversees the technical programs of the NBS/Boulder Laboratories. These Laboratories conduct research in time and frequency, quantum physics, and thermodynamics for the National Measurement Laboratory and in materials science for the Institute for Materials Science and Engineering. The Laboratories also carry out programs for the National Engineering Laboratory in electromagnetics, thermophysical properties, and fluid dynamics.

Dr. R.A. Kamper, Director (3237)*

Office of the Associate Director for Programs, Budget, and Finance

The Office of the Associate Director for Programs, Budget, and Finance plans, develops, and evaluates Bureau-level programs and formulates and carries out policies and strategies for programmatic, budgetary, and financial matters. It develops techniques for and coordinates the review of technical and overhead programs; serves as the NBS Director's staff for Bureau-level, programmatic budget formulation and execution and finance matters; and develops and maintains mechanisms to monitor planned and actual uses of resources by providing integrated, evaluated information on program progress, opportunities, and resources to the NBS Director. In addition, the Office advises management on significant changes and deviations and recommends program, budget, finance, and accounting priorities to the NBS Director.

Dr. P.L.M. Heydemann, Associate Director (3361)

Program Office
Dr. A.H. Sher, Chief (3137)

Budget Office
Mr. T.A. Gary, Budget Officer (2544)

Office of the Comptroller
Vacant (2814)

Office of the Director of Administration

The Office of the Director of Administration directs the management of Bureau-wide facilities, information systems, and management and administrative services including information resources and publications services; procurement, administrative computing, technical and public information functions; personnel, management analysis, health, safety, and security services as well as physical plant, facilities, and space management. The Office also decides on policies and plans and directs actions to assure that these services are responsive to the needs of the technical programs.

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Mr. K.E. Bell, Deputy Director (3444)

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Mr. A.C. Lewis, Chief (3494)

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Mr. R.S. Franzen, Chief (3112)

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Mr. O.H. Tobey, Chief (3384)

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Plant Division
Mr. J.N. Brewer, Chief (2825)

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Mr. F.P. McGehan, Acting Executive Officer (3955)*

Instrument Shops Division
Mr. D.W. Cook, Chief (3855)*

Plant Division
Mr. R.L. Rodger, Chief (3886)*

Institute for Materials Science and Engineering

The Institute for Materials Science and Engineering (IMSE) provides the nation with a central basis for uniform physical measurements, measurement methods, and measurement services basic to the processing, microstructural characterization, properties, and performance of materials. It provides government, industry, universities, and consumers with standards, measurement methods, data, and quantitative understanding concerning metals, polymers, ceramics, composites, and glasses. IMSE also obtains accurate experimental data on the behavior and properties of materials under service conditions to assure effective use of materials.

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Fracture and Deformation Division
Dr. R.P. Reed, Chief (3870)*

Polymers Division
Dr. L.E. Smith, Chief (3734)

Metallurgy Division
Dr. E.N. Pugh, Chief (2811)

Reactor Radiation Division
Dr. R.S. Carter, Chief (2421)

National Measurement Laboratory

The National Measurement Laboratory (NML) provides the national system of physical and chemical measurements; coordinates the system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical and chemical measurements throughout the nation's scientific community, industry, and commerce. NML also furnishes advisory and research services to other government agencies; conducts physical and chemical research; develops, produces, and distributes Standard Reference Materials; and provides standard reference data and calibration services.

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Dr. C.W. Reimann, Deputy Director for Resources and Operations (2878)

Standard Reference Data

Dr. D.R. Lide, Jr., Director (2467)

Measurement Services

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Office of Standard Reference Materials
Mr. S.D. Rasberry, Chief (3479)

Office of Physical Measurement Services
Mr. E. Garner, Chief (2805)

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Dr. J.D. Simmons, Deputy Director (2001)

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Dr. B.N. Taylor, Chief (2701)

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Dr. R.A. Haines, Deputy Director (2711)

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Dr. R.A. Durst, Acting Deputy Director (2852)

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Organic Analytical Research Division
Dr. W.E. May, Chief (3778)

Gas and Particulate Science Division
Dr. H.L. Rook, Chief (2886)

Institute for Computer Sciences and Technology

The Institute for Computer Sciences and Technology (ICST) develops computer standards, conducts research, and provides scientific and technical services to aid federal agencies in the selection, acquisition, application, and use of computer technology to improve effectiveness and economy in government operations in accordance with Public Law 89-306, relevant Executive Orders, and other directives. ICST manages a government-wide program for standards development and use, including management of federal participation in ADP voluntary standardization activities. In addition, ICST provides technical support in the development of federal ADP management and procurement policies, the selection and direction of federally sponsored computer research and development, and the resolution of computer utilization issues.

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Center for Programming Science and Technology

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Ms. H.M. Wood, Chief (3553)

Systems and Software Technology Division
Mr. A.L. Hankinson, Chief (2208)

Center for Computer Systems Engineering

Mr. R.P. Blanc, Director (3817)

Systems and Network Architecture Division
Dr. J.F. Heafner, Chief (3537)

Systems Components Division
Vacant (2705)

National Engineering Laboratory

The National Engineering Laboratory (NEL) furnishes technology and technical services to users in the public and private sectors to help to solve national problems in public interest. NEL conducts research in engineering and applied science in support of these efforts, builds and maintains competence in the necessary disciplines required to carry out this research and technical services, and develops engineering data and measurement capabilities. NEL also provides engineering measurement traceability services, develops test methods and proposes engineering standards and code changes, develops and proposes new engineering practices, and develops and improves mechanisms to transfer results of its research to the ultimate user.

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Mr. S. Kramer, Deputy Director (3233)
Dr. G.A. Sinnott, Associate Director for Technical Evaluation (3235)

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Mr. G.P. Lewett, Chief (3694)

Law Enforcement Standards Laboratory
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Office of Product Safety Technology
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Electrosystems Division
Dr. O. Petersons, Chief (2328)

Electromagnetic Fields Division
Mr. C.K.S. Miller, Chief (3131)*

Electromagnetic Technology Division
Dr. R.A. Kamper, Chief (3535)*

Semiconductor Electronics Division
Dr. K.F. Galloway, Chief (3541)

Center for Manufacturing Engineering

Dr. J.A. Simpson, Director (3421)
Dr. D.A. Swyt, Deputy Director (3421)

Factory Automation Systems Division
Mr. H.M. Bloom, Chief (2461)

Fabrication Technology Division
Mr. R.T. Penn, Chief (2436)

Automated Production Technology Division
Mr. D.S. Blomquist, Chief (3565)

Precision Engineering Division
Dr. R.J. Hocken, Chief (2577)

Robot Systems Division
Dr. J.S. Albus, Chief (2181)

Center for Building Technology

Dr. R.N. Wright, Director (3377)
Mr. J.G. Gross, Deputy Director (3375)

Structures Division
Dr. C.G. Culver, Chief (2196)

Building Physics Division
Dr. T. Kusuda, Chief (3637)

Building Equipment Division
Dr. J.E. Hill, Chief (3465)

Building Materials Division
Dr. G.J. Frohnsdorff, Chief (3704)

Center for Fire Research

Dr. J.E. Snell, Director (3143)
Mr. J. Winger, Deputy Director (3143)

Office of Fire Research Resources
Dr. R.S. Levine, Chief (3845)

Fire Safety Technology Division
Dr. A.J. Fowell, Chief (3255)

Fire Measurement and Research Division
Dr. R.G. Gann, Chief (2963)

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Mr. J. Hord, Director (5108)*
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FINAL REPORT

The Status of Emerging Technologies: An Economic/Technological Assessment to the Year 2000

JUNE 1987

U.S. DEPARTMENT OF COMMERCE
C. William Verity, Secretary
National Bureau of Standards
Ernest Ambler, Director

The Department of Commerce has concluded, in a review of emerging technologies and their future impact on the economy, that American businesses lag behind many of their foreign competitors, especially the Japanese, in exploiting technological breakthroughs.

The review was ordered by Deputy Secretary Clarence J. Brown in April 1986 to identify the new technologies that will lead to new products or processes, analyze their commercialization, and recommend means of reducing the barriers. It is based on an assessment by technical experts and agency heads within the Department. They studied scientific and industrial plans and the commercialization process here and abroad.

Once the list of technologies was determined, the experts determined their probable contribution to the gross national product by the year 2000. While recognizing this as an imprecise measure requiring some subjective forecasting, the Department believes it to be the best proxy to judge economic impact. Although the technologies are ranked in terms of high, moderate or low impact, the terms are relative; all are expected to play a significant role in future growth.

Identifying the technological opportunities and their probable economic effect is not difficult. The real problem facing U.S. companies is converting these opportunities into real economic success. The review's primary focus is upon identifying ten barriers to commercialization and making recommendations for overcoming them. The recommendations require action by all sectors of American life, sometimes unilaterally and occasionally together.

The barriers to commercialization are also ranked in order of importance. The two most important are inadequate tax incentives and the high cost of capital. The remaining barriers include two that require actions by individual companies. The Department found that there is a lack of integration and communication among functions within companies, and it also cites companies for being too complacent and dependent on the domestic market for growth opportunities.

The recommendations include fostering participative management by employees, training managers in the production process, eliminating provisions in foreign tax laws that discriminate against U.S. products, and updating business school curricula. They also reiterate recommendations of President Reagan's competitiveness initiative, such as those regarding improving export controls, reforming product liability and tort laws, and lifting antitrust restrictions.

Since the list of technologies was determined, there have been significant and highly publicized breakthroughs in the field of superconductors -- materials that have zero electrical resistance. Several developments must be achieved before their economic potential can be realized, particularly an improvement in the current-carrying capacity of these materials. Until it is known whether this is possible, superconductors should be considered a potential emerging technology.

The accompanying appendices describe in detail the technologies, barriers, and recommendations.

APPENDICES

APPENDIX A - DESCRIPTIVE TABLES

Table 1 - Emerging Technologies (4 pages)

Table 2 - Emerging Technologies Ranked by Economic Impact

Table 3 - Generic Barriers to Achieving Maximum Benefits from Emerging Technologies

APPENDIX B - DETAILED DESCRIPTIONS OF BARRIERS

APPENDIX C - RECOMMENDATIONS OF METHODS TO OVERCOME BARRIERS

Table 1

EMERGING TECHNOLOGIES

Technology	What does it do new or better?	Applied to what products or processes?	Used by What Major Industries?
1. Advanced Materials			
A. Ceramics	Better high temperature strength-to-weight properties	Heat engine components, turbine blades, heat shields	Automotive & aircraft engines
(high performance structural and electronic ceramics)	Better dielectric & optical properties	Electronic substrates, integrated optics	Electronic components
B. Polymer Composites	Higher strength-to-weight ratio	Structural components	Aerospace, automotive, ind. const.
(high strength fiber reinforced plastic resin)	Design flexibility because of spatial asymmetry	Structural components	Aerospace, automotive, ind. const.
C. Metals	Improved strength & high-temp performance	Structural components Super conducting components	Manufactured components
(rapid solidification, & metal matrix composites)	Improved magnetic properties	Electro-magnetic equipment	Electrical machinery
2. Electronics			
A. Advanced Microelectronics	Improved performance in speed, size	Semiconductor devices	Electronic & optical components & systems
(enhanced VLSI and VHSIC chips)	Improved magnetic properties	Information storage	Information processing
	Higher efficiency photovoltaic conversion	Solar cells	Energy generation

Technology	What does it do new or better?	Applied to what products or processes?	Used by What Major Industries?
B. Optoelectronics (optical fiber and light wave processing)	Improved performance in speed, size, capacity, and security	Electronic equipment, information processing	Communications & computers
	Higher density information storage	Computer systems of all sizes	Computers
C. Millimeter Wave Technology	When replacing radio systems it frees RF spectrum for other uses	Voice & data communication systems	Telecommunications carriers & corporate use for private circuits
3. Automation			
A. Manufacturing (computer integrated and flexible systems)	Flexible reconfiguration of production processes	All manufacturing processes	All manufacturing
	Integrated control of all production operations		
B. Business and Office Systems (computer applications within an organization)	Efficient information storage, retrieval, & exchange	Networking, word processing, & data base management	All organizations
C. Technical Services (computer applications in the provision of commercial services)	Efficient high-volume information storage, retrieval & exchange	Information retrieval and distribution, data base management, education and training	Financial services, electronic mail, telecommunications, professional service

Technology	What does it do new or better?	Applied to what products or processes?	Used by What Major Industries?
4. Biotechnology			
A. Genetic Engineering	Improved diagnostic and therapeutic drugs	Health Services	Medicine, Pharmaceuticals
(design & production of highly selective agents)	Improved plants, pesticides, & animal supplements	Foods and pesticides	Agriculture Food processing
	Neutralize pollutants	Environmental control processes	Chemical manufacturing & treatment
B. Biochemical Processing	Improved control of chemical processes, outputs, and yields	Chemical separations and reactions, biosensors	Chemical manufacturing
5. Computing			
A. Computing Equipment	Faster, lower-cost computing	Information processing and computer control	Potentially all.
(supercomputers, parallel processing, computer arch.)			
B. Artificial Intelligence Techniques	Improved computer replication of human judgment	Information processing and computer control	All applications using computers
(includes expert systems, natural language, and robotic control)			

Technology	What does it do new or better?	Applied to what products or processes?	Used by What Major Industries?
6. Medical Technology			
A. Drugs (other drugs are included in category 4 - Biotechnology)	Improved immunology and treatment	Health Services	Medicine, Pharmaceuticals
B. Instruments & Devices	Improved diagnostic and therapeutic systems	Magnetic Resonance Imaging & CAT scanning, radiation treatment	Medicine
7. Thin Layer Technology (semiconductor applications also are included in Electronics)			
A. Surfaces & Interfaces	Improved control and yield of chemical reactions	Chemical catalysis	Chemical manufacturing, food processing
	New electronic & optical properties	Semiconductor devices, surface modification and coatings	Electronic components, computers
B. Membranes	New chemical properties, better chemical separation techniques	Chemical separations	Chemical manufacturing, food processing

Table 2

EMERGING TECHNOLOGIES RANKED BY ECONOMIC IMPACT

Group A	(Highest)	Advanced Materials; Composites
		Biotechnology; Genetic Engineering
		Electronics; Optoelectronics
		Electronics; Advanced Microelectronics
		Computing; Computing equipment
		Automation; Manufacturing
Group B		Automation; Business and Office Systems
		Biotechnology; Biochemical Processing
		Medical Technology; Drugs
		Advanced Materials; Ceramics
		Automation; Technical Services
		Computing; Artificial Intelligence Tech.
		Medical Technology; Devices
Group C		Thin Layer Technology; Membranes
		Advanced Materials; Metals
		Thin Layer Tech.; Surfaces & Interfaces
		Electronics; Millimeter Wave Technology

Table 3

GENERIC BARRIERS TO ACHIEVING MAXIMUM ECONOMIC BENEFITS FROM EMERGING TECHNOLOGIES

1. High costs of capital funds in the U.S. relative to foreign competitors.

2. Tax incentives for U.S. companies relative to foreign competitors to deploy emerging technologies (including the stability of tax regulations).

3. Poor integration of manufacturing, design, and R&D functions.

4. Inadequate laws, regulations, and enforcement protecting intellectual property rights in the U.S. or overseas.

5. Complacency and dependence on the domestic market.

6. Restrictive trade policies in foreign markets.

7. Federal or State regulations on corporate activities intended to protect the public health and safety (e.g., building codes, environmental laws, drug approval regulations, and occupational health regulations).

8. Export controls on advanced technologies and high-technology products.

9. Restraints and uncertainty caused by product liability and tort laws.

10. Anti-trust restrictions against cooperative ventures for marketing or production methods. There may still be perceived barriers against cooperative R&D, but legal restrictions against procompetitive R&D were eased by legislation in 1984.

APPENDIX B

DETAILED DESCRIPTIONS OF GENERIC BARRIERS TO ACHIEVING MAXIMUM ECONOMIC BENEFITS FROM EMERGING TECHNOLOGIES

1. High costs of capital funds in the U.S. relative to foreign competitors.

Higher interest rates, lower debt-equity ratios, cultural practices, and tax laws combine to make the effective cost of capital funds for U.S. firms up to twice as high as their Japanese competitors. For example, U.S. savings rates, as a percentage of GNP, have historically been, and continue to be, among the lowest of developed countries (and about half that of Japan). Recent declines in the value of the dollar relative to foreign currencies have reduced some capital cost differentials, but the above factors combine to keep that differential high.

2. Tax incentives for U.S. companies relative to foreign competitors to deploy emerging technologies (including the stability of tax regulations).

Foreign countries continue to employ a variety of incentives to encourage the growth of new technologies. These range from subsidies for the conduct of R&D to import protection of the products derived from the new technologies, at least in their early marketing stages. U.S. firms receive few such subsidies. Some predict that recent changes in the tax law will have a stultifying effect upon venture capital, thus denying U.S. firms access to a previously major source of funding for new high-technology firms.

Frequent changes have made it difficult for U.S. businessmen. Drafting of regulations often lag behind legislation significantly. These changes and delays have created an air of uncertainty in business planning: uncertainty is always an anathema to the businessman.

3. Poor integration of manufacturing, design, and R&D functions.

For rapid movement of new technologies through the functions of R&D, design, product development, and production, it is necessary to have effective communication among these functions. Lack of willingness and opportunity of key technical staff to move with the emerging technology from R&D into manufacturing, for example, has been common in U.S.

organizations, although much improvement has occurred in recent years. A contributing factor in the U.S. has been the lower status, reflected in lower salaries and recognition, given to manufacturing relative to other branches of engineering.

Lack of cooperation and integration among institutions in the U.S. is just as important a barrier as among functions within a firm. For example, more rapid application of new technologies could be the result of closer coupling of firms to technical activities in Universities and Federal laboratories, and from intercompany cooperation to jointly address generic or structural technical problems of a longer-term nature. In this category would fall the classic Government research (carried out by NBS, NOAA, and NTIA) to provide technical data and standards that industry needs to design reliable new products/processes, but single firms do not have the incentive, expertise, or funds to develop themselves.

The Japanese are said to be particularly strong in integrating functions; this may partly account for the rapid speed with which their firms introduce new products into the market. Rotation of staff among these functions in Japan also helps this integration process.

4. Inadequate laws, regulations, and enforcement protecting intellectual property rights in the U.S. or overseas.

U.S. businesses rely upon strong intellectual property protection to realize the benefits of emerging technologies. In fact, the rate of development of emerging technologies may well depend upon patents as incentives and security for R&D or marketing investment, and upon trademarks to build and protect reputations for quality. Barriers exist where laws, regulations or enforcement procedures are inadequate. When innovation is neither rewarded nor encouraged, markets are either forfeited, left untapped, or are underdeveloped. Examples of domestic barriers include (1) the inadequacy of the statutory 17-year patent term for certain agricultural and pharmaceutical products which are subject to extensive premarket testing, and (2) the absence of effective protection for process patent holders against imports of products made abroad under the patented process.

On the international front, it is well recognized that many countries do not offer adequate intellectual property protection and, in some cases, actually sanction abuse of intellectual property rights. This would include, for example, a nation's outright appropriation of foreign-owned technologies or of creative and artistic works. This robs the inventor or creator and, of course, the associated business concern of any possibilities of realization of world market potential.

5. Complacency and Dependance on the Domestic Market

This barrier encompasses the attitudinal problems generated by the size and ready availability of the U.S. market for new products and services -- the lack of an immediately apparent need to compete with Japan and other countries head-to-head in the international marketplace. American companies, separately and in joint ventures, must aggressively seek export opportunities abroad and anticipate challenges in the U.S. from new foreign competitors. This barrier also encompasses the attitudinal differences toward "risk taking" between U.S. and Japanese firms and the cultural differences in approaches to production and marketing. The Japanese preference is to produce and market technological improvements in small increments, thereby gaining a foothold and experience in the marketplace. The U.S. approach is to complete as much research and development as possible before producing and marketing a new product which "leapfrogs" existing technology.

6. Restrictive Trade Policies in Foreign Markets

Restrictive trade policies take many forms -- laws, regulations and practices -- with an overriding consequence of protecting a home market from foreign products. Although most of these policies are sponsored by governments, business practices and social mores may also act as significant trade barriers.

Direct Government Practices are one type of policy affecting trade. Included here are:

- Tariffs and other import duties designed to protect a domestic market rather than to raise revenues.
    - Import licensing designed to create uncertainty, delays, and discrimination for foreign products.
    - Government procurement (i.e., buy national products)
    - Product development and export subsidies programs.

Indirect Government Practices are a second type of policy. Included here are:

- Standards codes, testing, labeling, and certification requirements which interfere with market availability and acceptance of foreign products.
- Local or domestic content (e.g. rules or origin)

requirements on foreign products which adversely affect technology and process innovations.
- Market reserve policies that designate certain markets for domestic products only.
- Disregard of intellectual property rights by foreign governments which undermine the ability to exploit markets with new products.

Non-trade and Non-government Measures and Practices are a third type. Included here are:

- Public health and safety laws that indirectly restrict the importation of foreign products.
- Local and national distribution systems that discriminate against foreign products through interlocking relationships among manufacturers, wholesalers, and financial institutions.

7. Federal or State regulations on corporate activities intended to protect the public health and safety (e.g., building codes, environmental laws, occupational health regulations, and drug approvals).

Emerging technologies generally require, somewhere in their development and production, some form of environmental and/or health clearance or regulation. This will occur on the Federal or State levels depending on which of the Federal regulation(s) apply.

Those technologies involving large-scale use of new materials, particularly in the broader electronics categories, will have to continue to meet the existing water, air and disposal requirements. In the case of new and exotic materials, such as the new semiconductor compounds (e.g. Gallium Arsenide), OSHA regulations are constantly being revised to protect against potential hazards, while EPA has control of various emissions through clean air and clean water legislation.

Solid waste reclamation also will enter into the cost of using new technologies. Disposal of new composite materials as scrap in products that have reached the end of their useful life, will impose a new set of costs and possible barriers. The present case of what to do with worn-out lead storage batteries is a good example of what might happen to a higher technology material with end-of-cycle toxicity.

For those technologies involved in medical and health care, regulations covering production, product certification, standards, OSHA considerations and disposal add to the burden of time/testing, as well as to the cost of meeting stringent health and environmental standards. The current issues surrounding the regulation and testing of genetically-altered naturally occurring organisms is a prime example of an emerging technology in the early stages of development.

The costs and time delays involved are further exacerbated if competing countries have less stringent certification and environmental requirements. Technologies in those countries are often put into production faster, thus putting U.S. suppliers at a competitive disadvantage. There are several recent examples in the pharmaceutical industry of the effect of these differences.

8. Export controls on advanced technologies and high-technology products.

While the need for control of the export of technology for purposes of U.S. national security has been clearly established, the costs attributable to "over-control" are also now becoming more apparent. That is, the Executive Branch's inability to decontrol goods and technology -- that are no longer strategic or are available from foreign competitors--is now seen as inhibiting our ability to remain technologically superior to our international competitors as well as contributing to the erosion of our defense industrial base . The Department of Commerce is trying to establish interagency procedures that will facilitate the decontrol to take place as Congress intended.

9. Restraints and uncertainty caused by product liability and tort laws.

With increasing frequency, claims are made that innovation and ability to compete are retarded in the U.S. by product liability and tort laws. The resulting uncertainty and instability have brought about a need for reform. Reasons include:

- A patchwork of 50 different state laws on product liability. Cases based on similar facts, but tried in different states, can produce strikingly different and contradictory results.
- The enormous transaction costs for all parties involved in litigation.
- The high costs of insurance for product-liability related protection.

Over the past 20 years our product liability law has moved away from fault as its basic guiding principle. The Commerce Department has taken the position that as a matter of fairness to manufacturers and as an incentive to them to construct new and safe products, businesses should generally be held liable only for behavior based on fault.

10. Anti-trust restrictions against cooperative ventures for marketing or production. There may still be perceived barriers against cooperative R&D, but legal restrictions against procompetitive R&D were eased by legislation in 1984.

Many U.S. anti-trust restrictions have been in place, substantially unchanged, for over 75 years. In these times of strong foreign competition and worldwide markets, U.S. firms are at a disadvantage when compared to foreign firms not subject to such strong, legal strictures. Production economies not envisaged when the original laws were enacted are now possible. These economics permit firms jointly to build and operate facilities at lower cost, thus improving world-competitive positions. Facilities housing flexible automated manufacturing systems are one example, but other shared facilities are also possible. Joint production by large firms, joint marketing of the products, and mergers of such large firms are subject to close scrutiny by U.S. Federal agencies, even though they may increase efficiency. This is viewed as an anachronism, particularly in the light of foreign practice.

Cooperative funding of procompetitive R&D was eased by changes enacted in 1984 which, among other things, reduced damages to be assessed to losses actually incurred. These changes are still not as widely known as they might be, with the result that some cooperative U.S. ventures are not being undertaken in fear of anti-trust prosecution.

APPENDIX C

RECOMMENDATIONS OF METHODS TO OVERCOME BARRIERS

BARRIER: HIGH COST OF CAPITAL IN THE U.S. RELATIVE TO FOREIGN COMPETITORS

Efforts to reduce Federal budget deficits should continue because of negative effects of the high deficits on capital markets and on interest rates.

State and local level efforts to meet local capital needs should be encouraged. The creation of venture capital pools would help increase the availability of capital for the new, high-risk developments that sometimes have very large innovation and competitive payoffs. Investment rebates and other incentives might also be used.

Actions should be taken to increase aggregate savings in the U.S. Additional tax incentives (beyond the recent tax reform), direct appeal to savers, and other actions could increase savers willingness to save rather than consume. Increased savings levels are necessary to help increase capital supply and lower interest rates. The U.S. savings level is much lower than in competitor nations.

BARRIER: TAX INCENTIVES FOR DEVELOPMENT OF NEW TECHNOLOGIES

In order to encourage rapid commercialization of technological advances, any future changes in the tax law should focus on the incentives available for long-term investment in all factors of the production, marketing, and distribution processes. Changes in cost recovery provisions should not force U.S. companies into a competitive disadvantage. American businesses must have confidence that major tax changes will not be made repeatedly.

The tax laws of foreign countries should be analyzed to determine if they discriminate against U.S. products being sold there. Discriminatory effects should be alleviated through negotiation or, if necessary, compensated through legislation.

BARRIER: POOR INTEGRATION OF MANUFACTURING, DESIGN, AND R&D MARKETING FUNCTIONS

All managers should have a grounding in the basic production process of the company. Beyond this, managers should receive cross-functional training so they have at least a minimal appreciation of finance, personnel, technology development, marketing, as well as production.

Top management must foster attitudes throughout management staff that foster flexibility, change, innovation and adaptability.

Business schools must update curricula to train business students in the total process -- from R&D to marketing and servicing. Business students must see any particular specialization within the fullest context of what is required for corporations to achieve maximum productivity.

BARRIER: INTELLECTUAL PROPERTY PROTECTION

Industrial firms in the U.S should take great care in transferring their technology and other intellectual property to foreign firms. For protecting the competitiveness of the nation as a whole, firms should establish safeguards against non-economic transfers.

Export control procedures should be changed to include intellectual property protection agreements and concerns, so that sales by U.S. firms are protected and enhanced.

Insist other nations protect U.S-owned intellectual property. Treaties, reciprocal agreements, tariffs, and other mechanisms used by the U.S. government in dealing with other nations should incorporate strong intellectual property provisions. U.S. laws could be strengthened to insure reciprocity and to prevent unapproved imports of products made abroad by processes patented in the U.S. Enforcement in other countries is often the weakest link in the protection process.

Ownership of rights stemming from collaborative research should be clarified. The goal is to eliminate uncertainty and thus maximize the incentives to rapidly commercialize technological developments by U.S. firms. Similarly, actions should be taken to assure that ownership rights and other benefits from Federally-funded research flow to U.S. organizations.

Ways should be sought to obtain payments from foreign graduate students for the intellectual property they benefit from while doing research in the U.S.

BARRIER: COMPLACENCY AND DEPENDENCE ON THE DOMESTIC MARKET

We must foster entrepreneurial risk-taking. Several steps can be taken. Promote greater ownership by executives of corporate stock so that executives become owners, not simply managers. Include employees in "participative management" so that more decisions are made by those closest to production operations. Incentive systems must be improved so that more employees feel they have a greater stake in the success of the company.

Shift emphasis in our business schools so that executive responsibilities are taught more within the context of "owners" responsibilities rather than "management" responsibilities.

We must promote a greater sense of the "common good" so that government, management and labor interact on a basis of achieving positive goals rather than on the historic adversarial basis.

We must foster the awareness that there is no longer anything such as a purely "domestic" market. What we think of as the U.S. domestic market is, in fact, part of the global market. Thus as soon as a product leaves the shipping dock, it has hit the world market, even if it is only being shipped across town. This perspective must permeate all management levels.

BARRIER: RESTRICTIVE TRADE POLICIES IN FOREIGN MARKETS

Adaptability to foreign preferences should be improved by U.S. firms. The result should be U.S.-made products that better meet the special preferences of consumers in other nations and better performance in the marketing/distribution systems overseas. Increased exports and reduced trade deficits are the obvious goal.

Foreign languages should be introduced earlier into the U.S. educational process, so that our citizens will have a greater ability to understand foreign needs/preferences, and have an increased ability to successfully do business overseas.

BARRIER: FEDERAL AND STATE REGULATIONS FOR PROTECTION OF HEALTH AND SAFETY

Wherever possible, domestic regulations (from such sources as EPA, OSHA, FDA, and SEC) should be reduced and simplified in order to minimize their negative effects on industry's use of new technology. In some cases, foreign competitors have an advantage of less stringent or loosely enforced regulations.

A better balance should be achieved between the desirable safety goals of domestic regulations and the economic costs to U.S. manufacturers and businesses. In addition to the added costs, firms often have the application of new technology or marketing of new products delayed significantly. In the current global economy, we should recognize that economic viability is as important a national goal as public safety. The key is to balance these goals in a meaningful way.

BARRIER: EXPORT CONTROLS ON ADVANCED TECHNOLOGIES AND HIGH-TECHNOLOGY PRODUCTS

The January 1987 President's Competitiveness Initiative directs the Cabinet to review the export controls program and provide recommendations to achieve the following:

- Decontrolling those technologies that offer no serious threat to U.S. security;
- Strengthening enforcement controls on those technologies that could harm U.S. security;
- Eliminating unilateral controls in those areas where there is widespread foreign availability;
- Reducing the time required to acquire a license by at least one-third and implementing a fair, equitable, and timely dispute resolution process;
- Seeking agreement with our allies for concrete actions to be taken which will make export control procedures more uniform and enforcement more rigorous;
- Seeking overall to level the competitive playing field while strengthening multinational controls over products and technologies that can contribute to Soviet military capabilities; and
- Recognizing the continued improvement in U.S./People's Republic of China (PRC) relations and the commitment of the PRC to protect sensitive technology, and working with our allies to further liberalize high technology trade with China.

BARRIER: RESTRAINTS AND UNCERTAINTY CAUSED BY PRODUCT LIABILITY LAWS

The January 1987 President's Competitiveness Initiative proposes several methods to overcome this barrier. Proposed legislation would:

- Retain a fault-based standard of liability;

- Eliminate joint and several liability except in cases where defendants have acted in concert;
- Limit noneconomic damages to a fair and reasonable amount;
- Provide for periodic, instead of lump sum, payments of damages for future medical care or lost income;
- Reduce awards in cases where a plaintiff also is compensated by other sources, such as government benefits;
- Reduce transaction costs by limiting attorneys' contingent fees to reasonable amounts on a sliding scale; and
- Encourage litigants to resolve more cases out of court.

BARRIER: ANTI-TRUST RESTRICTION AGAINST COOPERATIVE VENTURES

The January 1987 President's Competitiveness Initiative proposes several methods to overcome this barrier. The statutory proposals include:

- Amending Section 7 of the Clayton Act to distinguish more clearly between pro-competitive mergers and mergers that would create a significant probability of increased prices to consumers;
- Limiting private and Government antitrust actions to actual (rather than treble) damages, except for damages caused by overcharges or underpayments;
- Removing unwarranted and cumbersome restrictions on interlocking directorates;
- Clarifying the application of U.S. antitrust laws in private cases involving international trade; and
- Requiring that any antitrust claims remaining against other defendants after a partial settlement in a case be appropriately reduced.

Remarks by Deputy Secretary of Commerce Clarence J. Brown
News Briefing on Emerging Technologies
June 9, 1987

Good morning. It is no secret that this country has a trade problem. Likewise, it is no secret that at least part of the problem has been our inability to take full commercial advantage of scientific and technological developments made in the United States. Time and time again we have seen foreign competitors, most notably, but not exclusively, the Japanese, turn our technological developments into their commercial product successes.

I think it is fair to say that the country has awakened to this dilemma. The national attention to the general subject of competitiveness is evidence of our awakening. The President has put forward a comprehensive package of proposals to deal with this problem, and the Administration is taking a series of steps to improve our situation.

This morning, I want to take a longer view of our trade and technology position. I want to draw attention to the future and to the technologies that just now are emerging from the laboratory and seem particularly promising in both a scientific and commercial context.

I am firmly convinced that America's ability to exploit a new set of emerging technologies with huge market potential in the year 2000 and beyond will play a big role in determining the country's economic successes or failures well into the next century.

Recognizing the importance of these technologies, I asked a group of technical experts and top officials from Commerce Department agencies to examine the latest scientific and technological advancements and to report to me on which technologies seemed especially important, what barriers stood in the way of their commercialization within the United States, and what steps could be taken to remove those obstacles.

This group, headed by Dr. Ernest Ambler, director of the National Bureau of Standards, who is with us this morning, studied scientific and industrial plans and the commercialization process here and abroad.

They identified 17 emerging technologies in 7 major groups which are expected to lead to new products or processes in the future. Among other things, the review panel considered the expected contribution of each technology to the gross national product.

Here is the list the group came up with:

SHOW POSTERBOARD WITH EMERGING TECHNOLOGIES LIST

Advanced materials. These include high-performance ceramics, polymer composites, and advanced metals. They will bring improvements in automotive and aircraft engines, electronic components, electrical machinery, and manufactured components.

Electronics. Here the panel singled out advanced microelectronics critical to semiconductor devices, optoelectronics -- which covers optical fiber and lightwave processing vital to advances in communications and computers -- and millimeter wave technology, which can be used in voice and data communication systems.

Automation. Computer-integrated and flexible systems for manufacturing are on the list, as are computer applications in business and office systems as well as applications for commercial services such as financial transactions and electronic mail.

Biotechnology. Both genetic engineering -- for improved diagnostic and therapeutic drugs and agricultural and food applications -- as well as biochemical processing for chemical manufacturing, are critical technologies.

Computing. Supercomputers, artificial intelligence, and a variety of other computing techniques deserve a category of their own, with potential applications to literally every industry in the United States.

Medical Technology. Progress in new medical drugs and instruments and devices for improved diagnosis and treatment of illness is fast-paced and promises to continue into the next century. We are certain to see new technologies that are nothing more than scientific concepts today.

Thin Layer Technologies. Electronic components, chemical manufacturing and food processing, and a variety of other industrial operations are expected to benefit from rapid advances in using ultra-thin layers of chemicals to improve the capabilities of devices and products.

The list is not meant to be cast in concrete. For example, in the few weeks since the original list was put together, there have been significant and highly publicized breakthroughs in the development of superconductors -- materials that have absolutely no electrical resistance. Basic scientific questions and great technical problems need to be solved before we can realize the economic potential of these high-temperature superconductors, so for now they must remain a potential emerging technology.

But all you have to do is to look at one possible application for these superconductors, the transmission of electrical energy, to realize the enormity of their promise. We now spend $160 billion a year on electrical power in this country, and we waste a full 20 percent of that power due to losses in transmissions. If high-temperature superconductors can be developed to the point where they can be substituted for conventional electrical transmission wires, we could save more than $30 billion a year.

When I talk about the potential of emerging technologies, that is what I am talking about, a revolution that could affect every industry in America and around the globe.

But there are barriers.

SHOW POSTERBOARD WITH GENERIC BARRIERS

This list of generic barriers to achieving maximum economic benefits from emerging technologies should look familiar.

The relatively high costs of capital funds and the less favorable tax incentives in the United States compared to foreign competitors top the list.

Management's focus on short-term, rather than longer range, goals for returns on investments, poor integration of manufacturing, design, and research and development functions within U.S. firms, and the lack of cooperation among American institutions, hurt our chances of exploiting emerging technologies.

So do inadequate laws, regulations, and enforcement protecting intellectual property rights in the United States or overseas.

Complacency and a dependence on the domestic market -- the lack of awareness of the need to compete with Japan and other countries head-to-head in the international marketplace -- are a basic stumbling block.

Restrictive trade policies in foreign markets,

Federal or state regulations on corporate activities,

Export controls on advanced technologies and high-technology products,

Restraints and uncertainty caused by product liability and tort laws, and

Anti-trust restrictions -- real and perceived -- against cooperative ventures for R&D, marketing, or production.

All are formidable barriers to the commercialization of these emerging technologies.

Now, what do we do about breaking down these barriers? You have a description of the recommendations in your press kits. They include:

- -- continued vigilance to reduce federal budget deficits and to avoid high interest rates which affect the cost of capital
- -- creation of venture capital pools at the state and local levels
- -- additional tax incentives and other actions to increase aggregate savings
- -- a commitment to making future changes in the tax laws focus on the incentives available for modernization investment in all stages of production, marketing, and distribution
- -- fostering participative management by employees
- -- training managers in the production process and updating business school curricula

-- eliminating provisions in foreign tax laws and regulations that discriminate against U.S. products, and

-- improving export controls, reforming product liability and tort laws, and lifting antitrust restrictions.

In a recent hearing before his Committee on Commerce, Science and Transportation, Senator Fritz Hollings complained, "America may still invest enough in research to win most of the Nobel Prizes, but the Japanese make all the profits on them." Well, we cannot let that continue to happen. As you can see by looking at the barriers and recommendations for commercializing emerging technologies, the government has an important role to play. But the private sector -- the people who work in and run America's factories and board rooms -- must take the lead.

This country has done enough looking back and talking about how many different areas of technology we have already lost to the commercial competition. Our look ahead at critical emerging technologies should be a warning that unless we pull together and take swift action now to break down the barriers to the commercialization of new technologies, we are going to be facing the same international trade problems we confront today right on into the next century.

We have made some progress. Although we neither talk nor read enough about them, this country has some wonderful success stories and some good things happening to show that businesses and even entire industrial sectors can and are taking decisive actions to improve the situation. We have firms joining together in research consortia, corporations cutting down on excessive managerial positions, and companies finding new market niches overseas.

We simply must be vigilant and make additional changes now if the country's economic future is to be bright when the new century arrives.

Now, I'd be happy to take any questions you may have.

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The Department of Commerce has concluded, in a review of emerging technologies and their future impacts on the economy, that American businesses lag behind many of their foreign competitors, especially the Japanese, in exploiting technological breakthroughs.

The review was ordered by Deputy Secretary Clarence J. Brown in April 1986 to identify the new technologies that will lead to new products or processes, analyze their commercialization, and recommend means of reducing the barriers. It is based on an assessment by technical experts and agency heads within the Department. They studied scientific and industrial plans and the commercialization process here and abroad.

Remarks by Deputy Secretary Brown in releasing the report are included.

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Senator **Sarbanes**. Thank you very much, Mr. Ambler. I would be remiss if I didn't start by acknowledging the fine work that's done at the National Bureau of Standards. It was my privilege to visit with you not long ago and it was a very informative and instructive visit.

I think perhaps you ought to take a moment or two to talk about the Baldrige National Quality Award. I know it's in your prepared statement, it would be helpful for you to discuss it. Is this the first year that it's to be awarded?

Mr. **Ambler**. Yes, sir. Well, we expect the first award to be made in approximately November 1988. We have set up in the Bureau of Standards to organize with the private sector, as the legislation calls for. The Secretary of Commerce has taken intense interest in this. He asks me about it every week, so he wants this to go. He's helped us do several things. He has obtained the assurance that the President himself will present the medal and now we are in the process of putting together all of the procedures that the legislation calls for—writing the criteria, setting up a board of examiners, a board of overseers, seeing how the funding can be raised from the private sector.

We have a very tight schedule between now and the spring when we have to have everything in place, but we are on schedule and I think we're going to make it work.

The reaction from within and outside the Government has been very positive. I think everybody wants to make this a very prestigious award, at least as prestigious as the Deming Award is in Japan, and that it will be of tremendous benefit in encouraging the pursuit of quality and disseminating ways to achieve quality.

Senator **Sarbanes**. Is there going to be one award? Is it going to be done by categories? Or will there just be one award for anybody and everybody?

Mr. **Ambler**. The three categories—manufacturing companies, service companies, and small business. In each of those three categories there may be given up to a maximum of two awards. So the maximum number of awards in toto would be six.

Senator **Sarbanes**. I think it does have tremendous potential for focusing national attention and I'm pleased to see the attention that apparently is being given to it.

On a much lesser scale, in Maryland, we give a productivity award. The Senate established the program and the Senators give productivity awards in their States. We've managed to attract considerable attention to our effort in Maryland and we focus a lot of attention on improved performance. I think it has had a good impact.

Of course, this is much larger in its dimensions and in its implications, but I think it is an important development and it's certainly a fitting tribute to Secretary Baldrige I might add.

Mr. **Ambler**. Yes. I don't suggest this for the record, but I have just been handed a fact sheet that we put together just over a week ago. This was when I was giving a briefing for the whole department on the award. And I would like to leave it with you so you or your staff can look over it.

Senator **Sarbanes**. Fine.

Mr. **Ambler**. If you have any questions about it, we are open for any comments or suggestions.

Senator **Sarbanes**. Is the award going to be presented at the White House or out at the National Bureau of Standards?

Mr. **Ambler**. We expect it will be at the White House given by the President.

Senator **Sarbanes**. Sometimes it might focus better attention if you got the President out to the National Bureau of Standards.

Mr. **Ambler**. I never thought of that, but I'll work on it, sir.

Senator **Sarbanes**. Well, it's an interesting possibility.

Mr. **Ambler**. Yes, sir.

Senator **Sarbanes**. Which of your programs, if you had additional funds, would you expand? I know that seems to be a very hypothetical question in the present environment. But if indeed someone came along and said, "We're prepared to give you additional funds," where would you put them in your own programs?

Mr. **Ambler**. Well, strangely enough in this environment—and I know whereof you speak because I've lived in that environment now for many, many years—this year, fiscal year 1988, the Bureau of Standards is being treated differently. Let me say from my own point of view much better in a budgetary sense. If you look at the President's budget, you will see a number of line items where we're allowed to request increases.

All of these are in areas of emerging technologies. For example, in bioengineering or automation. You know all the list of emerging technologies. And all of our requests fall into these areas and that's exactly where I think we should be going and having the National Bureau of Standards build on the kind of thing that it has proved it can do very well over the years is very important.

Now the new role that may be assigned is not clear yet because the legislation is in the trade bill and we don't know quite what is going to happen to that.

If we should get further responsibilities, this idea of working with State and local governments in regions I think is a very good idea. It's a thing we would like to do. But we shouldn't do that at the expense of the ongoing activity. You'll run the organization down. You'll draw on it without putting anything back if that were to happen. So I think it's very important that if we get that, it should not be at the expense of the ongoing activities—and ongoing in the sense of the mission being constantly responsive to new technologies and new developments.

Senator **Sarbanes**. At the hearing last week, we had testimony that much of the Japanese advantage in developing new products results from their ability to take widely available findings of basic research and create products cheaper and faster than Americans do.

Do you have any observations on that point?

Mr. **Ambler**. I think that statement is absolutely right. While we shouldn't be complacent, I don't think our science is hurting us. I don't even think our inventiveness is really hurting us. It's the speed with which—or the lack of speed with which we bring the technology into products and process.

Senator **Sarbanes**. Why do you think the Japanese are able to do it faster and cheaper?

Mr. **Ambler**. Well, I think I could say a lot about it but I don't want to go on and on. So what I would like to do is to say that, at the request of Deputy Secretary Brown in the Commerce Department, recently I chaired a Department-wide committee. The first objective was to identify the emerging technologies—what technologies are going to be important from an economic and business point of view by the year 2000. And we were able to do that. It's very easy to get a consensus on that very quickly.

Then to try to get some idea of the relative contributions they might make to the economy. That's a little more speculative, but you can have a stab at it.

Then the thing that we did as Mr. Brown asked us to do, which I think is very important, is to identify the barriers to the deployment of those technologies, and we did that. And that report has received a great deal of attention.

The barriers fall into two categories I would say. Those that fit into the macroeconomic barriers that you and your committee probably know more about than I do. The relative cost of capital, for example, here within the United States, and things like that. There are a number of them enumerated that you and the Commerce Department all talk about.

Then there are some microeconomic barriers there that, speaking as a technologist, we feel are very important, and not just us at the Bureau or in the Department. We get the same thing when we talk to our colleagues in universities or industry. That is the short-range view that we take of the whole process. I don't think our managers are any worse. I think that the rewards, financial or otherwise, are all short range. The Japanese don't take that view. They're concerned about the short-range view, but they are not afraid to invest in something 5 years or more down the pike. They are much more strategic. They see the global market. They're going for market share and they're willing to take a long pull in things like that.

There are other things. I think we can also learn from the Japanese when it comes to management, too, as a matter of fact. One of the things that I think a number of companies here are doing and doing successfully is a much closer integration of the development, the design, the manufacturing, and the marketing functions. Those have always been separate and it's led to inefficiencies because you have to go back and change things. It's the rework problem in a slightly different way. So having those work together is very beneficial.

One very distinguished manager of R&D of a big company in the United States told me that he has secured the biggest increase in productivity from his R&D by focusing on that very thing, getting these things together better.

So all of that is laid out in this report. But speaking as a technologist, I think the basic problem is we don't set out to grab the global market share over a long period of time. We're much too concerned with the quarterly statements and stuff like that and a lot of other things this committee knows plenty about.

Senator **Sarbanes**. Do you think there's an attitude in this country that we don't have a lot to learn from others, that we've been

No. 1 for a long time and therefore tend not to look outside in order to draw knowledge and guidance?

Mr. **Ambler**. I think that was the point of view. I don't really think it is now. I think there's an appreciation—well, I think there's always been an appreciation in the sciences of the world activity. But I think in the sense of learning so we can fix the things that are really hobbling us in our competition, yes, I think there's a lot of attention being given to it these days. I wouldn't say a tremendous amount of deployment, but the signs and directions are all very favorable and you see more and more companies and you hear more and more consultants on management lecturing on the Japanese way.

In fact, we had one such person, a former Assistant Secretary of Science and Technology, talk to us last week and he's doing exactly the same thing.

The old ideas, as you know, that were put forward by Mr. Taylor, that made the mass production in this country what it is—mass production, Charlie Chaplin modern times thing, with the headless worker, is gone. We're in the stage now where we need everybody's efforts both in mind and body to make an organization work, get them all involved. I think those lessons are starting to be learned.

Senator **Sarbanes**. Well, thank you very much, sir for your testimony. It's been very helpful and we appreciate it very much.

Mr. **Ambler**. Thank you, sir.

Senator **Sarbanes**. If the second panel would now come forward—Mr. Saloom, Mr. Flamm, and Mr. Burton. Mr Saloom, I think we will begin with you and then we'll just move right across the panel.

STATEMENT OF JOSEPH A. SALOOM, CHAIRMAN, COUNCIL ON RESEARCH AND TECHNOLOGY, AND SENIOR VICE PRESIDENT, M/A COM, INC.

Mr. **Saloom**. Thank you very much.

I am here today on behalf of 152 corporations, universities, research institutions, and associations that comprise the Council on Research and Technology, or CORETECH. I am chairman of CORETECH and also senior vice president of M/A COM, of Burlington, MA. We are grateful today for the opportunity to appear before you.

The subject of today's hearing, the commercialization of new and useful technologies, is of great importance to CORETECH. We spent a great deal of time this past year discussing among ourselves and with others how to improve and accelerate the process by which companies apply technology. U.S. companies, as we've heard many times, do not do this as well as we could or need to do if we are to remain competitive in international markets.

Just 2 days ago, on December 9, CORETECH's board of directors met and voted on our policy agenda for 1988 and beyond. Our policy concerns begin at the beginning of an idea and continue until that ideas' commercial viability is fully proved. In a moment, with your indulgence, I will describe to you in greater detail our recommendations on commercialization.

First, though, however, our board asked that I convey to you a message of extreme importance to us in the research community. It is really a plea. It's a plea for more stable R&D policies.

The United States, as I'm sure you will hear many times in this hearing, is the world's envy when it comes to research. Substantial investment in research beginning in the early 1940's and accelerating after Sputnik in the late 1950's, put us ahead in science and technology and helped propel us into a period of phenomenal economic growth.

However, it is clear to many of us who have spent our lives in science and technology that our work is being taken for granted. It is with great sadness that I must sit today before Congress with the distressing message that U.S. policy on research has, for the past two decades, been inconsistent, inadequate, and sometimes actually harmful.

The National Government has been long on rhetoric on science policy but woefully short on effective action. It's a concern that if this pattern of the past 20 years is allowed to continue, then I fear for our continued excellence in science and technology and the commercialization of our new and more useful products and processes.

Let me just list a few examples. First, there is the research and development tax credit. At the urging of Americans, Japan adopted a permanent R&D tax credit in 1966 to increase industrial R&D spending. The United States finally adopted a comparable policy in 1981 following nearly two decades of stagnant private R&D spending. Although the new credit was a demonstrable success, it was allowed to lapse in 1985. When renewed in 1986, it was reduced by 20 percent and effectively extended for only 2 years.

Second, there is Treasury Regulation 861. This provision, for those not familiar, requires companies to allocate part of their R&D expenditures to foreign source income regardless of where the R&D is conducted. This provision is widely believed—and I certainly believe—to actully encourage companies to move their R&D abroad. If you're going to be taxed as if the R&D is conducted abroad, you should consider conducting that R&D abroad. Congress enacted a series of moratoria to prevent implementation of the 861 regulation. Then, in August of this year, the latest moratorium ran out. Despite agreement by congressional leaders and the Treasury Department on a permanent compromise to resolve this longstanding problem, the budget negotiators knocked the compromise out of both the Senate and the House tax bills and the 861 regulation is now currently in effect.

No other country has a comparable provision. Rather, other industrialized nations offer attractive incentives to lure R&D to their shores.

The third issue is the state of our academic research infrastructure. The unique strength of the American research establishment lies in the coupling of advanced research with education in our universities. Yet, for the past 20 years, Federal support of university research facilities fell by 95 percent in real terms. At the same time, the National Science Foundation funding of basic research remained essentially unchanged. Pending legislation to correct these trends currently languishes in Congress, and progress appears to be stymied by unrelated issues.

In the meantime, other countries, such as Japan, have realized the intrinsic value of fundamental research and have taken steps to improve their basic research capabilities.

In short then, our plea is simple. As the conscience of Congress on economic matters, the Joint Economic Committee is in an excellent position to urge Congress to review its policies on science and technology and adopt clear, consistent incentives and programs. Few Members of Congress come out against research and development. Yet, when the crunch comes, as it did recently, R&D provisions are often pushed off the table. We hope that the Joint Economic Committee would highlight and criticize these troubling patterns.

Now let us look at commercialization in the economic context for a second. Our ability to successfully commercialize technologies depends on the health of the research community. It is also dependent on the health of the economy as a whole. We realize that even if all of CORETECH's policies were adopted, commercializing technologies requires a healthy economy, available capital, and vibrant markets.

Conversely, economists have demonstrated that productivity and economic growth are heavily dependent on innovation which, in our industrialized society, in turn depends on research and development. During times of economic sluggishness or downturn, we know companies often cut back of their R&D. This was the short-range view I think expressed here today. It seems Congress does the same thing on incentives and programs for science and technology. We fervently hope that, under the Joint Economic Committee's leadership and urging, Congress will see that during times of budgetary stress and trade deficits, more, not less, investment in R&D is needed.

Now to be a little more specific, let me just outline a few recommendations to accelerate and improve commercialization.

CORETECH has looked closely at specific ways to improve the commercialization process. With your permission, we would very much like to have our recommendations on commercialization become part of the record, and I have these here.

Senator **Sarbanes**. They will certainly be included.

Mr. **Saloom**. Thank you very much. I'll just outline them very briefly. First is technology transfer. Recently it has become apparent that many of our companies have trouble transferring an idea from one division to another while the Japanese have become adept at technology transfer from one continent to another. Moreover, we tend to be lax at pursuing ideas discovered in other countries and using and improving upon them. We in CORETECH feel that this must change.

Like our other policy areas, successful technology transfer depends on private initiative. Our initial recommendations are therefore addressed to industry, and to academic institutions. A substantial number of our recommendations are addressed, however, to the Federal Government. In part, this is so because our organizational focus is on the Federal Government. Additionally, we believe that the National Government has a very significant role to play in accelerating and improving our commercialization process.

Specifically, in technology transfer—and this is just an outline and the recommendations are included in the prepared statement—the Federal Government should encourage through programs the development and testing of creative models of technology transfer. Importantly, the Federal Government can encourage and support the people-to-people exchanges between industry, universities, and government laboratories that are essential to technology transfer. Finally, the Government has a major role to play vis-a-vis foreign countries and should work to achieve a more equitable exchange of technology.

Second, we need specific programs and incentives on commercialization. Let me mention for a moment in this context the role of advanced manufacturing technologies. All too often, we are beaten on the shop floor. Other countries elevate manufacturing to a technology and, in a myriad of ways, we need to do the same. I think the testimony this morning from the Bureau of Standards indicates that they have elevated manufacturing to a technology in itself. This approach reflects our ideas.

Third, we need to pay more attention to cooperative research. We call for new technology partnerships in areas where successful commercialization appears likely and we call for the removal of any remaining barriers, be they cultural, institutional, or legal, to cooperative research relationships.

Let me just conclude quickly. CORETECH members realized that our recommendations, taken singly, fall far short of the effort needed to meet the commercialization challenge. Taken together, however, we believe that they set us in the right direction. CORETECH's policy, I want to emphasize, is that the private sector should take the primary responsibility for commercializing new products, but we also feel the National Government has an extremely important role to play.

The National Government, we feel, must take stock and send a clear message to all parts of the research community—from those working on the very earliest concepts of an idea to those putting the finishing touches on a new product—that this work is essential to the future economic well-being and defense of our country.

Only clear, consistent, and supportive policies will provide the framework that is necessary to bring ideas out of American laboratories and into American factories and onto successful competition in world markets.

It is now time for Congress' performance, however, to match its rhetoric on research and development. Inconsistent, inadequate, and harmful policies nip good ideas in the bud and prevent their fruition.

We in CORETECH are committed to developing and helping to implement stable public policies that we can live with during the long haul. We feel we are all in this together. We cannot afford on-again, off-again tax incentives. We cannot afford to continue harmful regulations. We just cannot stand by and watch our academic research facilities deteriorate. We cannot idly hope that technology transfer will just happen. We have to understand it. We need stable public policies and we certainly need your help to make our laboratories the world's finest and our products the most competitive.

Thank you very much.

[The prepared statement of Mr. Saloom follows:]

PREPARED STATEMENT OF JOSEPH A. SALOOM

I AM HERE TODAY ON BEHALF OF THE 152 CORPORATIONS, UNIVERSITIES, RESEARCH INSTITUTES, AND ASSOCIATIONS THAT COMPRISE THE COUNCIL ON RESEARCH AND TECHNOLOGY, CORETECH. I AM CHAIRMAN OF CORETECH AND SENIOR VICE PRESIDENT OF M/A COM, INC. WE ARE GRATEFUL FOR THE OPPORTUNITY TO APPEAR BEFORE YOU TODAY.

THE SUBJECT OF TODAY'S HEARING, THE COMMERCIALIZATION OF NEW AND USEFUL TECHNOLOGIES, IS OF GREAT IMPORTANCE TO CORETECH. WE SPENT A GREAT DEAL OF TIME THIS PAST YEAR DISCUSSING AMONG OURSELVES AND WITH OTHERS HOW TO IMPROVE AND ACCELERATE THE PROCESS BY WHICH COMPANIES APPLY TECHNOLOGY. U.S. COMPANIES DO NOT DO THIS AS WELL AS WE COULD OR NEED TO IF WE ARE TO REMAIN COMPETITIVE IN INTERNATIONAL MARKETS.

JUST TWO DAYS AGO, ON DECEMBER 9, CORETECH'S BOARD OF DIRECTORS MET AND VOTED ON OUR POLICY AGENDA FOR 1988 AND BEYOND. OUR POLICY CONCERNS BEGIN AT THE BEGINNING OF AN IDEA AND CONTINUE UNTIL THAT IDEA'S COMMERCIAL VIABILITY IS FULLY EXPLORED. IN A MOMENT, WITH YOUR INDULGENCE, I WILL DESCRIBE TO YOU IN GREATER DETAIL OUR RECOMMENDATIONS ON COMMERCIALIZATION.

FIRST, OUR BOARD OF DIRECTORS ASKED THAT I CONVEY TO YOU A MESSAGE OF EXTREME IMPORTANCE TO US IN THE RESEARCH COMMUNITY. IT IS REALLY A PLEA.

NEED FOR STABLE R&D POLICIES

THE UNITED STATES IS THE WORLD'S ENVY WHEN IT COMES TO RESEARCH. SUBSTANTIAL INVESTMENT IN RESEARCH BEGINNING IN THE EARLY 1940s AND ACCELERATING AFTER SPUTNICK IN THE LATE FIFTIES PUT US AHEAD IN SCIENCE AND TECHNOLOGY AND HELPED PROPEL US INTO A PERIOD OF PHENOMENAL ECONOMIC GROWTH.

I WOULD LIKE TO POINT OUT THAT WE WERE NOT ALWAYS A WORLD LEADER IN SCIENCE. FROM 1901 TO 1941, FOR EXAMPLE, THE FIRST 40 YEARS OF NOBEL PRIZES, ONLY 17 AMERICANS RECEIVED THESE AWARDS FOR SCIENCE. IN THE FOUR DECADES FOLLOWING WORLD WAR II, AMERICANS RECEIVED 117 NOBEL PRIZES IN SCIENCE.

HOWEVER, IT IS NOW CLEAR TO MANY OF US WHO HAVE SPENT OUR LIVES IN SCIENCE AND TECHNOLOGY THAT OUR WORK IS BEING TAKEN FOR GRANTED. IT IS WITH GREAT SADNESS THAT I MUST SIT BEFORE

CONGRESS WITH THE DISTRESSING MESSAGE THAT U.S. POLICY ON RESEARCH HAS, FOR THE PAST TWO DECADES, BEEN INCONSISTENT, INADEQUATE, AND SOMETIMES ACTUALLY HARMFUL.

THE NATIONAL GOVERNMENT HAS BEEN LONG ON RHETORIC ON SCIENCE POLICY BUT WOEFULLY SHORT ON EFFECTIVE ACTION. IF THE PATTERN OF THE PAST TWENTY YEARS IS ALLOWED TO CONTINUE, THEN I FEAR FOR OUR CONTINUED EXCELLENCE IN SCIENCE AND TECHNOLOGY AND THE COMMERCIALIZATION OF NEW AND MORE USEFUL PRODUCTS AND PROCESSES.

LET ME GIVE YOU A FEW EXAMPLES.

FIRST, THERE IS THE RESEARCH AND DEVELOPMENT TAX CREDIT. AT THE URGING OF AMERICANS, JAPAN ADOPTED A PERMANENT R&D TAX CREDIT IN 1966 TO INCREASE INDUSTRIAL R&D SPENDING. THE UNITED STATES FINALLY ADOPTED A COMPARABLE PROVISION IN 1981 FOLLOWING NEARLY TWO DECADES OF STAGNANT PRIVATE R&D SPENDING. ALTHOUGH THE NEW CREDIT WAS A DEMONSTRABLE SUCCESS, IT WAS ALLOWED TO LAPSE IN 1985. WHEN RENEWED IN 1986, IT WAS REDUCED BY 20 PER CENT, AND EFFECTIVELY EXTENDED FOR ONLY TWO YEARS.

SECONDLY, THERE IS TREASURY REGULATION 861, THE PROVISION WHICH REQUIRES COMPANIES TO ALLOCATE PART OF THEIR R&D EXPENDITURES TO FOREIGN SOURCE INCOME REGARDLESS OF WHERE INCURRED. THIS PROVISION IS WIDELY BELIEVED TO ACTUALLY ENCOURAGE COMPANIES TO MOVE THEIR R&D ABROAD AND FOR YEARS, CONGRESS ENACTED A SERIES OF MORATORIA TO PREVENT ITS IMPLEMENTATION. THEN, IN AUGUST OF THIS YEAR, THE LATEST MORATORIUM RAN OUT. DESPITE AGREEMENT BY CONGRESSIONAL LEADERS AND THE TREASURY DEPARTMENT ON A PERMANENT COMPROMISE TO RESOLVE THIS LONGSTANDING PROBLEM, THE BUDGET NEGOTIATORS KNOCKED THE COMPROMISE OUT OF THE SENATE AND HOUSE TAX BILLS AND THE 861 REGULATION IS CURRENTLY IN EFFECT. NO OTHER COUNTRY HAS A COMPARABLE PROVISION. FURTHER, MOST OTHER INDUSTRIALIZED NATIONS OFFER ATTRACTIVE INCENTIVES TO LURE R&D TO THEIR SHORES.

THIRDLY, THERE IS THE STATE OF OUR ACADEMIC RESEARCH INFRASTRUCTURE. THE UNIQUE STRENGTH OF THE AMERICAN RESEARCH ESTABLISHMENT LIES IN THE COUPLING OF ADVANCED RESEARCH WITH EDUCATION IN OUR UNIVERSITIES. YET FOR THE PAST TWENTY YEARS, FEDERAL SUPPORT OF UNIVERSITY RESEARCH FACILITIES FELL BY 95 PERCENT IN REAL TERMS AND NATIONAL SCIENCE FOUNDATION FUNDING OF UNIVERSITY BASIC RESEARCH REMAINED ESSENTIALLY UNCHANGED. PENDING LEGISLATION TO CORRECT THESE TRENDS CURRENTLY LANGUISH IN CONGRESS, AND PROGRESS APPEARS TO BE STYMIED BY UNRELATED ISSUES. IN THE MEANTIME, OTHER COUNTRIES SUCH AS JAPAN HAVE REALIZED THE INTRINSIC VALUE OF FUNDAMENTAL RESEARCH AND HAVE TAKEN STEPS TO IMPROVE THEIR BASIC RESEARCH CAPABILITIES.

IN SHORT, OUR PLEA IS SIMPLE. AS THE CONSCIENCE OF CONGRESS ON ECONOMIC MATTERS, THE JOINT ECONOMIC COMMITTEE IS IN AN EXCELLENT POSITION TO URGE CONGRESS TO REVIEW ITS POLICIES ON

SCIENCE AND TECHNOLOGY AND ADOPT CLEAR, CONSISTENT INCENTIVES AND PROGRAMS. FEW MEMBERS OF CONGRESS COME OUT AGAINST RESEARCH AND DEVELOPMENT YET, WHEN THE CRUNCH COMES, R&D PROVISIONS ARE OFTEN PUSHED OFF THE TABLE. THE JEC SHOULD HIGHLIGHT AND CRITICIZE THIS TROUBLING PATTERN.

THE ECONOMIC CONTEXT FOR COMMERCIALIZATION

OUR ABILITY TO SUCCESSFULLY COMMERCIALIZE TECHNOLOGIES DEPENDS ON THE HEALTH OF THE RESEARCH COMMUNITY. IT IS ALSO DEPENDENT ON THE HEALTH OF THE ECONOMY AS A WHOLE. WE REALIZE THAT EVEN IF ALL OF CORETECH'S POLICIES WERE ADOPTED, COMMERCIALIZING TECHNOLOGIES REQUIRES A HEALTHY ECONOMY, AVAILABLE CAPITAL, AND VIBRANT MARKETS.

CONVERSELY, ECONOMISTS HAVE DEMONSTRATED THAT PRODUCTIVITY AND ECONOMIC GROWTH ARE HEAVILY DEPENDENT ON INNOVATION WHICH, IN OUR INDUSTRIALIZED SOCIETY, IN TURN DEPENDS ON RESEARCH AND DEVELOPMENT. DURING TIMES OF ECONOMIC SLUGGISHNESS OR DOWNTURN, COMPANIES OFTEN CUT BACK ON THEIR R&D. DURING TIMES OF BUDGETARY DURESS, IT SEEMS, CONGRESS CUTS BACK ON INCENTIVES AND PROGRAMS FOR SCIENCE AND TECHNOLOGY. WE FERVENTLY HOPE THAT, UNDER THE JEC'S LEADERSHIP AND URGING, CONGRESS WILL SEE THAT DURING TIMES OF BUDGETARY AND TRADE DEFICITS, MORE NOT LESS INVESTMENT IN R&D IS NEEDED.

RECOMMENDATIONS TO ACCELERATE AND IMPROVE COMMERCIALIZATION

CORETECH HAS LOOKED CLOSELY AT SPECIFIC WAYS TO IMPROVE THE COMMERCIALIZATION PROCESS. INTERNALLY, WE APPOINTED A SPECIAL TASK FORCE ON COMMERCIALIZATION WHICH MET FREQUENTLY IN 1987. WE HELD FOUR FORUMS ACROSS THE COUNTRY AND SOUGHT THE OPINIONS OF NEARLY 500 SCIENTISTS, ENGINEERS, AND BUSINESS AND ACADEMIC LEADERS. WE LEARNED A LOT. WITH YOUR PERMISSION, WE WOULD VERY MUCH LIKE TO HAVE OUR RECOMMENDATIONS ON COMMERCIALIZATION BECOME PART OF THIS HEARING RECORD. THEY CAN BE SUMMARIZED IN THREE MAJOR AREAS.

THE FIRST IS TECHNOLOGY TRANSFER. FOR MOST OF OUR HISTORY, WE HAVE HAD PRECIOUS LITTLE INCENTIVE TO TRY TO UNDERSTAND HOW A NEW IDEA BECOMES NEW PRODUCTS AND INDUSTRIAL PROCESSES. SOMEHOW, IT WAS ASSUMED TO JUST HAPPEN. MORE RECENTLY, THOUGH, IT HAS BECOME APPARENT THAT MANY OF OUR COMPANIES HAVE TROUBLE TRANSFERRING AN IDEA FROM ONE DIVISION TO ANOTHER WHILE THE JAPANESE HAVE BECOME ADEPT AT TECHNOLOGY TRANSFER FROM ONE CONTINENT TO ANOTHER. MOREOVER, WE TEND TO BE LAX AT PURSUING IDEAS DISCOVERED IN OTHER COUNTRIES AND USING AND IMPROVING UPON THEM. WE IN CORETECH FEEL THIS MUST CHANGE.

LIKE OUR OTHER POLICY AREAS, SUCCESSFUL TECHNOLOGY TRANSFER

DEPENDS ON PRIVATE INITIATIVE. OUR INITIAL RECOMMENDATIONS ARE THEREFORE ADDRESSED TO INDUSTRY AND ACADEMIC INSTITUTIONS. A SUBSTANTIAL NUMBER OF OUR RECOMMENDATIONS ARE ADDRESSED TO THE FEDERAL GOVERNMENT. IN PART, THIS IS BECAUSE OUR ORGANIZATIONAL FOCUS IS ON THE FEDERAL GOVERNMENT. ADDITIONALLY, WE BELIEVE THAT THE NATIONAL GOVERNMENT HAS A VERY SIGNIFICANT SUPPORT ROLE TO PLAY IN ACCELERATING AND IMPROVING COMMERCIALIZATION.

SPECIFICALLY, IN TECHNOLOGY TRANSFER, THE FEDERAL GOVERNMENT SHOULD ENCOURAGE THROUGH PROGRAMS THE DEVELOPMENT AND TESTING OF CREATIVE MODELS OF TECHNOLOGY TRANSFER. THE FEDERAL GOVERNMENT CAN ENCOURAGE AND SUPPORT THE KINDS OF PEOPLE-TO-PEOPLE EXCHANGES BETWEEN INDUSTRY, ACADEMIA, AND GOVERNMENT LABORATORIES THAT NEED TO OCCUR IN SUCCESSFUL TECHNOLOGY TRANSFER. FINALLY, THE GOVERNMENT HAS A MAJOR A ROLE TO PLAY VIS A VIS FOREIGN COUNTRIES AND SHOULD WORK TO ACHIEVE A MORE EQUITABLE EXCHANGE OF TECHNOLOGY.

SECONDLY, WE NEED SPECIFIC PROGRAMS AND INCENTIVES ON COMMERCIALIZATION. LET ME MENTION FOR A MOMENT IN THIS CONTEXT THE ROLE OF ADVANCED MANUFACTURING TECHNOLOGIES. ALL TOO OFTEN, WE ARE BEING BEATEN ON THE SHOP FLOOR. OTHER COUNTRIES ELEVATE MANUFACTURING TO A TECHNOLOGY AND, IN A MYRIAD OF WAYS, WE NEED TO DO THE SAME. OUR RECOMMENDATIONS INCLUDE SPECIFIC STEPS IN THIS REGARD, INCLUDING, FOR EXAMPLE:

- ESTABLISHING A FEDERAL DEMONSTRATION PROGRAM FOR DEVELOPING AND TESTING NEW COMMERCIALIZATION MODELS;
- ESTABLISHING A NEW FEDERAL FELLOWSHIP PROGRAM IN ADVANCED MANUFACTURING TECHNOLOGIES;
- EXPANDING THE R&D TAX CREDIT TO INCLUDE EXPENDITURES MADE TO DEVELOP AND IMPROVE MANUFACTURING PROCESSES; AND,
- MAKING THE R&D TAX CREDIT PERMANENT.

THIRDLY, WE NEED TO PAY MORE ATTENTION TO COOPERATIVE RESEARCH. THE BENEFITS OF COOPERATIVE RESEARCH ARE JUST NOW BEGINNING TO COME FORTH. COOPERATIVE RESEARCH VENTURES TAKE PLACE BETWEEN VARIOUS COMBINATIONS OF COMPANIES, UNIVERSITIES, RESEARCH INSTITUTES, AND GOVERNMENT LABORATORIES. THEY ARE IMPORTANT BECAUSE THEY CAN BE VERY INSTRUMENTAL IN FACILITATING TECHNOLOGY TRANSFER AND ENCOURAGING ECONOMIC EFFICIENCY IN RESEARCH. WE CALL FOR NEW TECHNOLOGY PARTNERSHIPS IN AREAS WHERE SUCCESSFUL COMMERCIALIZATION APPEARS LIKELY AND WE CALL FOR THE REMOVAL OF REMAINING BARRIERS, CULTURAL, INSTITUTIONAL AND LEGAL, TO COOPERATIVE RESEARCH. SPECIFICALLY, WE RECOMMEND:

- PROVIDING FEDERAL SEED GRANTS ON A MATCHING BASIS FOR TECHNOLOGY PARTNERSHIPS;

- MAKING COOPERATIVE RESEARCH ELIGIBLE FOR THE BASIC RESEARCH CREDIT;
- ESTABLISHING A FEDERAL PILOT PROGRAM TO DEMONSTRATE A SMALL BUSINESS UNIVERSITY RESEARCH PROGRAM;AND,
- MAKING THE BASIC RESEARCH CREDIT PERMANENT.

CONCLUSION

CORETECH MEMBERS REALIZED THAT OUR RECOMMENDATIONS, TAKEN SINGLY, FALL FAR SHORT OF THE EFFORT REQUIRED TO MEET THE COMMERCIALIZATION CHALLENGE. TAKEN TOGETHER, HOWEVER, WE THINK THAT THEY SET US IN THE RIGHT DIRECTION.

THE NATIONAL GOVERNMENT MUST, WE FEEL, TAKE STOCK AND SEND A CLEAR MESSAGE TO ALL PARTS OF THE RESEARCH COMMUNITY -- FROM THOSE WORKING ON THE VERY EARLIEST STAGES OF AN IDEA TO THOSE PUTTING THE FINISHING TOUCHES ON A NEW PRODUCT -- THAT THEIR WORK IS ESSENTIAL TO THE FUTURE ECONOMIC WELL BEING AND DEFENSE OF THE COUNTRY.

THE NATIONAL GOVERNMENT MUST, WE ALSO FEEL, SET POLICIES THAT ARE CONSISTENT AND THAT ARE SUPPORTIVE.

ONLY CLEAR, CONSISTENT, AND SUPPORTIVE POLICIES WILL PROVIDE THE FRAMEWORK THAT IS NECESSARY TO BRING IDEAS OUT OF AMERICAN LABORATORIES INTO AMERICAN FACTORIES AND ONTO SUCCESSFUL COMPETITION IN WORLD MARKETS.

CONGRESS' PERFORMANCE MUST NOW MATCH ITS RHETORIC ON RESEARCH AND DEVELOPMENT. INCONSISTENT, INADEQUATE, AND HARMFUL POLICIES NIP GOOD IDEAS IN THE BUD AND PREVENT THEIR FRUITION.

WE IN CORETECH ARE COMMITTED TO DEVELOPING AND HELPING TO IMPLEMENT STABLE POLICIES THAT WE CAN LIVE WITH DURING THE LONG HAUL. WE ARE ALL IN THIS TOGETHER. WE CANNOT AFFORD ON AGAIN, OFF AGAIN TAX INCENTIVES. WE CANNOT AFFORD HARMFUL REGULATIONS. WE CANNOT JUST STAND BY AND WATCH OUR ACADEMIC RESEARCH FACILITIES DETERIORATE. WE CANNOT IDLY HOPE THAT TECHNOLOGY TRANSFER WILL JUST HAPPEN. WE NEED STABLE PUBLIC POLICIES.
WE WANT AND NEED YOUR HELP TO MAKE OUR LABORATORIES THE WORLD'S FINEST AND OUR PRODUCTS THE MOST COMPETITIVE.

Senator **Sarbanes**. Thank you very much, sir. We will do all of the panel and then we'll take questions. Mr. Flamm, please proceed.

Mr. **Flamm**. I'm going to let Mr. Burton go first.

Senator **Sarbanes**. Fine.

STATEMENT OF DANIEL F. BURTON, JR., VICE PRESIDENT, COUNCIL ON COMPETITIVENESS

Mr. **Burton**. With your permission, Mr. Chairman, since both Ken Flamm and I are working on the same project at the council, I will outline the contours of our effort and then Ken will be more specific in certain areas.

The council would like to thank the Joint Economic Committee for giving us this opportunity to discuss the commercialization of technology and how it relates to U.S. competitiveness.

Specifically, what I would like to address is the Federal Government's role in facilitating the commercialization of technology. I am here as the vice president of the Council on Competitiveness, a private sector organization composed of CEO's from leading American companies, labor unions, and universities. The council is chaired by John Young, the chairman and CEO of Hewlett Packard Co.

Senator **Sarbanes**. Was the council an outgrowth of the——

Mr. **Burton**. The President's Commission on Industrial Competitiveness, yes, it was. Although the council is a private, nonprofit, whereas the President's Commission was a governmental effort.

Senator **Sarbanes**. We thought—at least I, for one, thought the report and recommendations of the President's Commission deserved a lot more attention and focus than unfortunately they received at the time, just to offer a predicate for your testimony.

Mr. **Burton**. Thank you very much. I think one of the primary purposes of the Council on Competitiveness is to see to it that the agenda items that were initially framed out in the President's Commission on Industrial Competitiveness move more into the stage of implementation.

The council has been in existence for over a year, and it has determined that a top priority in restoring U.S. economic competitiveness is enhancing the commercialization of technology.

Although the United States excels at basic research, we need to do a better job of translating new innovations into commercially successful products and processes.

The council recognizes that in the commercialization process, the primary responsibility lies with the private sector. Nonetheless, we firmly believe that government actions have a critical impact on the commercialization process and that the Federal Government needs to refocus its involvement in technology issues so that it better supports the commercialization of products and processes. In essence, I think it's the council's position that fostering the commercial application of new innovations should no longer be an incidental or a secondary objective of the Federal Government, but should be among our Federal R&D priorities.

Just as commercialization is extremely difficult to define, so I think it's extremely difficult to pinpoint one government program that can be geared to address it. The Federal Government influences the commercialization process on a broad front, both directly and indirectly. And it is our belief that in order to promote the commercialization of new technology, the U.S. Government must also act on a broad policy front. No one program can sort of solve commercialization problems. Instead, we need to come at it from many different directions.

In this regard, we think that the key to any effective solution is to regard the issue of commercialization of technology in the proper context and to develop appropriate Federal policy within a broad framework.

In recent years there has a been a great deal of government activity in restructuring technology programs. Nonetheless, it appears that there is no clear consensus yet on precisely what government programs should be in this area, and the council has launched a task force to examine the whole question of the Federal role in facilitating the commercialization of technology and to develop a private sector consensus which can then hopefully help guide government efforts in this area. We will be completing our work this spring and we would be glad to share our findings and recommendations with you at that point.

What I'd like to do very briefly this morning is to summarize the context in which we are addressing the commercialization problem and in which we think action needs to be taken.

First, we recognize up front that the macroeconomic environment and the educational environment have a tremendous impact on U.S. efforts to commercialize new innovations. Unless we can improve macroeconomic management and improve our education efforts in science and engineering, we are going to have a very difficult uphill struggle in improving private sector abilities to commercialize new innovations.

However, I am not going to address those two issues today. The council is focusing more on specific government programs. There are four primary areas that we think need to be considered in developing Federal policies to assist the commercialization of innovations.

The first is improving the climate for research. The second is improving government support systems. The third is improving the management of technology information flow. And the fourth category is reforming the Federal technology policy apparatus. I will just briefly walk through those four areas before I turn the microphone over to Ken Flamm who is cochairing the panel.

Under the category of improving the climate for basic research, we recognize that basic research is a necessary but insufficient condition for the commercialization of technology. The United States has the world's premiere basic research base, but I do not think that we can redirect efforts away from basic research or let our basic research institutions lapse. I think the fact that Japan is focusing heavily on basic research in its science and technology programs today, having borrowed a page from U.S. efforts, demonstates just how important basic research is to U.S. economic competitiveness.

At the same time, however, the United States must do more than simply basic research. I think the connections between basic research and competitiveness and basic research and the commercialization of innovations are more indirect and often long term.

In this regard, the Federal R&D budget must include more focus on issues that are directly related to industrial competitiveness. The numbers on the Federal R&D budget I think were cited earlier by yourself in these proceedings—70 percent of the Federal R&D budget goes to defense programs. Of the remaining 30 percent, I think the National Institutes of Health accounts for almost half of those expenditures, and the National Institutes of Health, the Department of Energy, NASA, and NSF account for almost 80 percent of the remaining civilian R&D budget. It's our opinion that we should reexamine this budget, with the issue of industrial competitiveness in mind, to see if more efforts cannot be made specifically to build up U.S. industrial competitiveness.

In this regard, research facilities and equipment must also be upgraded. There has been a dramatic dropoff in Federal funding for university research facilities over the past 20 years and we think that this needs to be corrected.

In the second category, that of Government support systems, we think there are three areas that should be taken into consideration. The first is general incentives. The second is targeted support. The third is cooperative ventures.

Under general incentives, I think it's well known that the United States spends more on R&D than any other nation, both as a percentage of GNP and in absolute terms. When you net out the defense component, Japan and West Germany spend more in terms of a percentage of their GNP, but it should also be noted that American corporations tend to invest relatively less in R&D than their counterparts in West Germany and Japan.

In this regard, we think it's terribly important that the generic incentives for American corporations to invest in R&D be strengthened and I think CORETECH has developed some admirable policies along these lines.

In the area of targeted support, the concern in the past is that the Federal Government is incapable of picking winners and losers and therefore should stay out of the business of targeting support on specific technologies or industries, but I think there is also an emerging consensus at this point that there are some actions that the Federal Government can take in targeting support that are either procompetitive or focus on generic manufacturing processes that have wide application to industry and therefore can contribute to industrial competitiveness and assist the commercialization process without getting caught up in the thicket of picking winners and losers.

Finally, in the area of cooperative ventures, cooperative ventures have long been a standard of Japanese technology policy. The United States is moving in that direction. I think at this point we are exploring and experimenting with several different forms. The council thinks that this is a terribly important area and we should continue to support efforts here.

The third category is that of management of technology information flow. I'll be very brief here. I think there are three issues often discussed in this area—technology transfer from Federal laboratories to the private sector, intellectual property protection, and access to international technical information.

The core issue that all three of these three areas have in common is how to manage information, how to control access to it, how to secure it when it is of a proprietary nature. We need to continue to think about government policies in this area since they set the framework for which action is taken.

The final issue area or category is that of reforming the Federal technology policy apparatus. We think there are two concerns here. The first is reducing unnecessary government barriers. I think we have seen progress in recent years in this area in terms of reducing antitrust barriers which block cooperative R&D, and continued vigilance needs to be given in this area.

The final category is effectively organizing and coordinating government technology programs. Here, the Young Commission has some experience. They came out with a recommendation to reorganize government science and technology programs. The council has not yet taken a position in that area, however, we do believe that it's important to have a program which drives the reorganization rather than vice versa.

In concluding, I would just like to reiterate three principal statements here. The first is that the commercialization of innovations and technology is critical to U.S. competitiveness and we need to do a better job in this area.

The second is that the U.S. Government should make fostering the commercialization of R&D an important R&D priority.

The third is that U.S. Federal action should be framed within a broad policy context. No one program can address the issue of commercialization of technology. I think action on a broad policy framework and consistent over several years is the key to success in this area.

Thank you very much.

Senator SARBANES. Thank you, sir.

Mr. Flamm, please proceed.

STATEMENT OF KENNETH FLAMM, SENIOR FELLOW, THE BROOKINGS INSTITUTION

Mr. FLAMM. Thank you, Mr. Chairman. I'm pleased to be able to come before you today. I'd like to begin by pointing out that I am somewhat uneasily wearing two hats today. The first hat is as a cochair of the task force on commercialization of the Council on Competitiveness. In that capacity, I am in a somewhat curious position, since we are currently in the midst of an effort to find a consensus and can't really speak for any definitive position that either the task force or the council has yet taken.

The second hat I wear, in which I can be somewhat freer in my opinions, is that of an individual who has been looking at questions of Federal science and technology policy, and trade and investment issues in high-technology industries. I am an economist at the Brookings Institution and I have recently summarized some of my views in a submission to this committee, the concluding chapter of a book on government's role in the development of computer technology in the United States, Western Europe, and Japan. That book was published by the Brookings Institution in June. A companion volume, "Creating the Computer," which is an economic history of the computer industry, is going to come out in February.

Instead of merely pointing out the agenda that we're going to be discussing in our task force, I would like to talk briefly about some of the issues that I believe will be coming up, things that I think deserve long and hard thought.

I would preface my remarks by concurring with much of the analysis that I've heard already here today: that U.S. high-technology industries really were a set of industries that largely emerged from our World War II experience. That was a watershed in our economy and in our policies. Prior to World War II, for example, something like 15 to 20 percent of research and development was paid for by the Federal Government. After World War II, it rose to close to two-thirds and today, of course, it's over one-half.

Our high technology industries attained a position of leadership in the postwar decades that was built on that massive research and development investment. Through most of those decades, we really had no competition. But today it's a different story.

The future of our standard of living hinges on our response. I think there's a widespread perception of need for some kind of consistent, coherent way of addressing that problem, and I take the existence of the council, and the task force which I am serving on, as proof of the increasing recognition throughout our society that this is a critically important issue. Wearing my hat as a private individual commenting on the sociology of all that I see today, it strikes me that there's been a substantial shift in attitudes toward Federal support for technology and the Federal role in the support of technology. The variety of organizations that are testifying here today are rather eloquent testimony to that fact.

Let me just briefly talk about what I think the issues raised by the Federal role are. I think one easy way of thinking about it is to think in terms of three issues. One is the objectives of the Federal Government in getting involved in the area of technology; the second is the functions that are served by the organizations that are set up by the Federal Government to address technology issues; and the third issue is the organizational aspects, how you go about organizing and mobilizing the Federal Government to look at technology issues.

I think there's a variety of good ideas that are floating around in Washington today. Many of those ideas are of an experimental nature. We're talking about undertaking experiments that we really haven't tried before. I think the odds of success are best if we have a thought-out and coherent approach to those problems, and that is what I would like to emphasize today.

First, I'd like to start with the question of objectives; that is, why is it that the Federal Government is involved and what should it be doing?

The first point is that the issue that comes up in the economic literature to which the Federal Government should clearly address itself is the question of appropriability; that is, the extent to which private firms can reap the benefits of research and development investments.

There is broad agreement that the extent to which private firms can capture a return on investment in technology varies widely with the type of investment in technology, whether we're talking about basic research or applied research or development effort. The general thinking is that it's in development that private firms are most able to capitalize on investment in technology, whereas in the more basic kinds of research, it's very difficult for a private firm to capture the benefits of its investment.

Therefore, though they may underly competitive advantage for a firm and an industry as a whole, it's difficult for any individual firm to have sufficient motivation to undertake those kinds of research investments where the returns are difficult to capture.

Thus, it seems that one immediate role of the Federal Government is to encourage, to provide incentives or to fund R&D investments, in areas where the private sector is unlikely to do so, not because it's not socially valuable to do so but because it's difficult to capture returns privately. That means areas like basic, long-term research. That means highly risky, very experimental, radical kinds of research projects. It also means that when the Federal Government does get involved in funding R&D, it really ought to be looking at precisely those kinds of research projects that private industry is least disposed to do. That is, more precommercial research and applied research projects.

It probably is not the role of the Federal Government to get involved in development projects at the commercialization stage and I think most everyone today will agree on that point.

Another objective of the Federal Government ought to be to encourage socially productive cooperation among firms. To some extent, this can eliminate duplication among the efforts among different firms in areas where it's not going to lead to private advantage on the part of any individual firm. At the same time, there's obviously a Federal role in ensuring that cooperative, necessarily collusive efforts don't lead to anticompetitive practices down the line. The natural fit between encouraging private cooperation and at the same time ensuring that those efforts do not lead to any social cost further down the line is through some form of direct participation in those efforts.

Another point which has come up repeatedly is the question of infrastructure. If you look at the history of science and technology policy in this country, you repeatedly see examples of a whole broad class of specialists being created as a result of an explicit Federal effort. I think, for example, of the massive investment we made in training computer scientists and materials scientists in the 1960's, and the fact that our prowess in computers today and the optimistic forecast we have for advances in superconductivity build on the infrastructure that was created by Federal policies in the 1960's.

Finally, I would point out that there's an informational function that the Federal Government serves, that it can collect information, especially abroad, where it's relatively difficult for private and smaller firms to tap into information on what is going on, and to disseminate it.

The final point I'd like to make on the question of objectives is that historically we've been rather bashful about linking Federal policy in the area of technology to commercial objectives, to making our firms successful in commercial markets. Typically, we've had to justify Federal policy in this area in terms of some mission-oriented objective, be it energy, be it defense, be it health. Today, I think we are at the point where we can recognize that investing in the basic infrastructure underlying competitiveness for our industries also is an objective. It always has been an objective to some extent. We have never stated so explicitly.

The second area is the question of functionality. What kind of functions should Federal organizations involved in commercialization of technology be thinking about? Briefly, information gathering, scanning the technological horizon, is something certainly in which government can play some productive role; facilitation of joint R&D ventures is a topic that comes up over and over again. It's an obvious area for the Federal Government to be involved in. By the same token, some watchdog should oversee Federal moneys that are spent on projects of this sort. And there clearly is also a public interest whenever companies come together in a cooperative way. Again, this ought to be a function of whatever Federal organization implements this set of policies.

Finally, the Federal Government really ought to have a contact point for industry. One of the problems with Federal policies in the past has been that the agenda really has not had a commercial orientation. There ought to be some way for industry to discuss the kind of projects that it thinks relevant to its commercial future, that it regards as appropriate for a Federal role in precompetitive, more basic kinds of research. And there ought to be some contact point in the Federal Government for industry to come with that agenda and negotiate how the Government can serve as a facilitator.

Finally, I'd like to briefly talk about organizational considerations. It seems to me that once having defined the functions of an organization devoted to facilitating commercially oriented technology development, that the organization should be specifically designed to serve these objectives. Among other things, it ought to be fairly flexible, reasonably quick moving, and reasonably small. I would say that DARPA, the Defense Advanced Research Projects Agency, or perhaps the President's Special Trade Representative's Office, might be an organizational model for a small, flexible, quick-moving organization. It would not serve as a dictatorial heavy hand on what is underway, but rather a facilitator, a contact point, an oversight agency, a watchdog for the public interest.

And it's also quite reasonable to suggest some technological capability ought to be attached to that agency. The National Bureau of Standards has come up repeatedly in discussions of this sort, and I think the National Bureau of Standards has a sterling historical record and a great deal of talent that could more adequately be exploited in this type of function.

Finally, I would conclude by briefly observing that this is an absolutely critical issue on which a lot hangs. I think we are gradually coming to realize that and I hope these issues attain an even higher profile because they are utterly crucial to the next decades of economic growth for the United States.

Thank you.

[The joint prepared statement of Messrs. Burton and Flamm, together with an article by Mr. Flamm, follows:]

JOINT PREPARED STATEMENT OF DANIEL F. BURTON, JR., AND KENNETH FLAMM

SUMMARY

- The Council on Competitiveness has determined that a top priority in restoring U.S. economic competitiveness is enhancing the commercialization of technology. Although the United States excels at basic research, we need to do a better job of translating new innovations into commercially successful products and processes.

- Although the primary responsibility for commercializing new technology lies with the private sector, government actions have a critical impact on the commercialization process. The Federal Government needs to refocus its involvement in technology issues so that it better supports the commercialization of new products and processes.

- Just as commercialization is difficult to define, so is it difficult to pinpoint government programs that directly facilitate the commercialization of technology. The Federal Government influences the commercialization process on several different levels, both directly and indirectly. Commercialization is not a discrete issue, and no one program can effectively address it. Instead, we must make incremental improvements in the array of programs that affect the commercialization of technology. The key to any solution is to regard the issue in the proper context and to develop appropriate policies within a broad framework.

- The Federal Government is moving to restructure its technology programs, but there is no clear consensus on appropriate government actions. The Council has launched a project on commercialization to develop a private sector consensus for the Federal Government role in facilitating the commercialization of technology. The Council will complete work on this project and release its findings and recommendations in the Spring of 1988.

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Thank you Mr. Chairman. We are pleased to be here today to discuss the commercialization of technology and how it relates to U.S. competitiveness. Specifically, we will address the Federal Government role in facilitating the commercialization of technology. We are representing the Council on Competitiveness, a private sector organization composed of chief executives from leading American companies, labor unions and universities. The Council is chaired by the President and Chief Executive Officer of the Hewlett Packard Company, Mr. John Young.

Technology has traditionally been one of our greatest competitive strengths, providing a major source of exports and accounting for a significant portion of U.S. productivity gains. In many ways, the United States remains preeminent in science and technology. We house the world's premier scientific community. The fraction of Nobel prizes awarded to Americans has continued to rise. U.S. scientists continue to be responsible for major new advances in knowledge. Students from around the world come to learn in American universities.

The problem we face is taking full advantage of our scientific strengths. There is a general consensus in academic, industrial and government circles that the United States is failing to capitalize on its tremendous scientific resources. This failure is usually described as an inability to commercialize technology effectively. Frequently, major new advances made by the American scientific establishment are not successfully carried into the market place by U.S. firms, and too often the efficient, low-cost production of new products takes place in other countries.

Because of the significant technological strides made by other nations, the United States can no longer take technological superiority for granted. From a government point of view, this means that fostering the commercial uses of technology can no longer be viewed as incidental or secondary to other objectives. The Federal Government must do more consciously to promote the commercialization of new innovations.

There is no one indicator that sums up the U.S. failure to successfully commercialize new innovations. Instead, a number of different indicators must be considered: patents, high tech trade, our education profile, industrial performance, and product development. Some of these indicators are briefly described below.

- The percentage of U.S. patents received by U.S. residents dropped from over 80 percent in 1965 to 55 percent in 1986. Between 1966 and 1984, two-thirds of the increase in U.S. patents awarded to foreign nationals went to the Japanese. As a consequence, the share of U.S. patents held by Japanese residents almost doubled between 1977 and 1985. In 1986, Japanese residents were awarded 17.7 percent of U.S. patents.

- In 1986, the traditional U.S. surplus in high-technology manufactures trade was transformed into a deficit for the first time.

- In recent years, more than half of the engineering Ph.D.s in the United States have been granted to foreign students. Ten percent of the nation's engineering faculty positions are currently vacant. If the United States continues to attract students to science and engineering at the 1983 rate, we will graduate almost 700,000 fewer scientists and engineers over the next twenty years than in the past twenty.

- American industries built around technologies developed in the United States, such as consumer electronics and semiconductors, are threatened by foreign competition.

- The United States has failed to capture many of the economic rents on the commercialization of innovations produced here, such as the transistor, video cassette recorder, color television, and integrated circuits.

If we are to improve U.S. competitiveness in international markets, the U.S. Federal government must systematically facilitate the commercial application of new innovations. Existing government programs must be improved, and new national initiatives considered. Although it is premature for the Council to provide recommendations in this area, we can offer a framework within which government actions should be considered.

In addressing the problem, it is critical to bear in mind that real progress will be achieved only if the issue of commercialization is approached on many different fronts. The Council has developed a framework for understanding the problem and determining how the Federal government can promote the commercialization of technology. The framework has four basic components: 1)Improving the Climate for Research, 2)Strengthening Government Support Systems, 3)Improving the Management of Technology Information Flow, and 4)Reforming the Federal Technology Policy Apparatus. These issues are described below.

I. IMPROVING THE CLIMATE FOR RESEARCH

Objective: A strong research base (people, facilities and equipment, programs, etc.) that promotes not only the advancement of scientific knowledge and national defense objectives, but also enhanced U.S. industrial competitiveness.

The Federal research and development budget is an important national resource that can be drawn on to maintain and improve the competitiveness of American industry. Despite heavy investments by U.S. companies in R&D (about $61 billion in 1987), the magnitude of international competition in some industries has raised concern that the R&D efforts financed by American firms will fall short of what is required. The U.S. Government spends about as much on R&D each year as all of American industry combined. In the President's proposed 1988 budget, $69.4 billion in budget authority was requested for R&D. Currently about 70 percent of Federal R&D funding is classified as national defense. Federal funding for civilian R&D accounts for the remaining 30 percent.

A strong basic research base is a necessary condition for U.S. competitiveness. A forceful Federal role in support of basic scientific research is widely accepted, based on the premises that such research underlies continuing developments in technology and that economic incentives are insufficient to assure that private firms will invest in adequate levels of basic research. Over the last decade, government civilian R&D spending has shifted to emphasize more basic research.

The connection between basic research and competitiveness, however, is indirect, long-term and uncertain. To be relevant to industry, research must be directed toward technical problems and market needs. Unless research is targeted on industrial needs, simply funding more will not improve U.S. competitiveness. The new scientific knowledge that results from basic research generally enters the public realm where it is available to all users, including our foreign competitors. Furthermore, much basic research is conducted by universities and colleges that traditionally have had little motivation to address research problems relevant to industrial technology or to transfer research results to industry when they are relevant. To be effective, emphasis on basic research must be complemented by programs that focus on carefully targeted and applied R&D.

Despite increased public support for basic research, the proportion of Federal civilian R&D funding that is directly relevant to competitiveness remains limited. It is difficult to determine with precision how much Federal civilian R&D funding is directed toward promoting competitiveness and how directly relevant it is, but according to one study, in FY 1985 only about ten percent of total Federal R&D expenditures was spent on applied research and development of commercial significance.

This problem is compounded by the fact that over the past twenty years, while many of our foreign competitors have been aggressively building up their R&D infrastructure, U.S. Federal funding for university research plant and facilities has declined by 95% in real terms. As a result, we face a deterioration of our nation's research facilities and aging and obsolete research infrastructure in our academic institutions.

II. IMPROVING GOVERNMENT SUPPORT SYSTEMS FOR INDUSTRIAL R&D

Government support systems for Industrial R&D can be divided into three areas: 1)General incentives, 2)Targeted support and 3)Cooperative ventures. Each of these is discussed below.

1. General Incentives for Civilian Industrial R&D

Objective: Encourage industrial R&D to further U.S. competitiveness and move relevant research toward commercialization.

The U.S. R&D budget is by far the largest in the world, and the gross R&D/GNP ratio is equal to the highest of other countries. U.S. R&D is sharply distinguished from its two main competitors, Japan and West Germany, in two ways: 1)the U.S. non-defense R&D/GNP ratio is considerably lower than in either country, and 2)American industry funds a lower percentage of R&D.

The emphasis on defense R&D in recent years has necessarily implied a relative shift away from direct government support for civilian R&D. Although tax support for industrial R&D continues to be available, the R&D tax credit has not become a permanent part of the Tax Code.

2. Targeted Support for Sector-Specific Technology Development Programs

Objective: Advance key technologies in existing or emerging strategic industrial sectors.

As a general principle, U.S. Federal support of technology does not focus on specific civilian industrial sectors or technologies. The preference instead has been for general policies, like taxation, or support for technology related to government missions, such as space or defense. Other countries have typically based their technology policies on opposite premises and tend to be organized, as in the Japanese case, around programs directed at particular sectors and related key technologies.

As the competitive position of U.S. companies has eroded in certain high-technology sectors, discussion has focused on the need for affirmative government support of strategic industries and technologies. Semiconductors and the proposal for Sematech provide the prototypical example of this issue. Proposals for government support of key generic technologies, such as superconductivity and automated manufacturing, are another example. The key technology approach is becoming more and more the focus of Japanese technology policy. These programs necessitate joint activity among firms and close cooperation with industry and government.

U.S. reluctance to support targeted R&D relevant to industrial needs stems from concern that the Federal government is not equipped to "pick winners and losers." The kind of industrially oriented applied R&D that seems to work in the United States is generic R&D -- that is, R&D that relates to problems relevant to industry, but is somewhat removed from specific commercial applications and is therefore of a nonproprietary nature. Although almost 60 percent of Federal civilian applied R&D funding goes for generic R&D, there is widespread concern that Federal funding for generic applied R&D relevant to industry needs is insufficient. Moreover, there is concern that Federal generic R&D is currently concentrated in a few areas that may be important, but are not necessarily those of greatest need to U.S. industry and the enhancement of U.S. competitiveness.

3. Facilitating Cooperative Technology Development

Objective: Build new, more effective linkages among firms, universities and government in order to develop and commercialize new technology.

Within the last few years, major changes have occurred in business and university attitudes and public policies toward cooperative technology developments. Cooperation at various stages of the development process is now often cited as an efficient means of sharing information, a low-cost strategy for R&D, and an effective response to external competitive challenges. Such attitudes have long pervaded technology policy in Japan and, to a lesser extent, in Europe.

The many cooperative ventures that have recently been formed in the United States can be divided into three types: 1)those that primarily involve American private companies, 2)those that bring U.S. industry together with other sectors, particularly universities, and 3)international joint ventures. Changes in antitrust laws have encouraged the first type, government funding for some cooperative endeavors supports the second, but little public policy attention has been directed toward the third.

Recognition of the importance of cooperative ventures to the technology strategy of individual U.S. companies and to the nation's competitiveness has motivated the Federal government to expand existing Federal support of these initiatives. These are relatively new ventures, however, and ways to maximize their effectiveness are still being explored.

III. IMPROVING THE MANAGEMENT OF TECHNOLOGY INFORMATION FLOW

Three issues have been raised by the Council's Task Force that can be categorized as having to do with managing the information flow of technology: 1)technology transfer, 2)intellectual property, and 3)equitable international technical access.

1. Technology Transfer

Objective: Maximize the utilization of knowledge generated by Federal science and technology programs.

Broadly defined, technology transfer involves sales, licenses and other means of diffusing technical expertise among firms in the private sector. It is widely agreed that technology transfer is most effective when it is a people-to-people process. The

Federal government's role in facilitating technology transfer is usually defined as moving the Federal laboratories' store of underutilized technical information into the private sector. The government addressed this issue in the Technology Transfer Act of 1986, although full implementation of this act remains a problem.

To frame the issue of how to maximize the effectiveness of the U.S. Federal laboratory system solely in terms of technology transfer, however, is to underestimate the problems surrounding the Federal laboratory system and its contribution to industrial competitiveness. The U.S. has over 700 national laboratories that receive one-third of total Federal R&D funding, employ more than a half-million scientists and engineers, and house some of the most expensive and sophisticated scientific equipment in the world. Mechanisms need to be established to improve the effectiveness of the Federal laboratory research system and to allow American industry to work more closely with the Federal labs on R&D relevant to U.S. competitiveness.

2. Increased Protection for Intellectual Property

Objective: Strengthen the incentive system for innovation by securing the rights of creators and owners of technology.

Strong intellectual property rights create, through legal protections for invention, an essential underpinning for innovation. Domestically, the level of legal protection has recently been augmented through several changes in patent and copyright law and government contracting policies. Major difficulties have arisen, however, in the international context. Copyright and trademark piracy is rampant in some countries, a situation new being addressed in treaty negotiations. Inadequate property right enforcement abroad is a corollary problem.

3. Achieving Equitable International Technical Access

Objective: Achieve reciprocity in access to world-wide technology for U.S. interests without compromising national security or impairing the openness of the American system.

Historically, most of the U.S. government scientific and technical enterprise has been open to foreign scientists, engineers, and industrial representatives. While the openness and rapid transmission of information in the American system are unique strengths, there is growing concern that foreign industries are profiting unduly form this openness without reciprocal benefits to U.S. interests abroad.

IV. REFORMING THE FEDERAL TECHNOLOGY POLICY APPARATUS

Objective: An effectively focused and coordinated government program that enhances the commercial application of technology and promotes U.S. competitiveness.

Two related issues have been identified in this category: 1)eliminating unnecessary regulatory constraints and 2)effectively organizing and coordinating Federal technology programs.

1. Eliminating Unnecessary Regulatory Constraints

Government regulations and bureaucratic procedures, though necessary, also sometimes pose unwarranted barriers to the commercialization of technology. Such barriers have a negative impact on U.S. competitiveness. Broad regulatory systems, such as antitrust and export controls, have been the subject of considerable discussion. Although limited antitrust exemptions now exist for research consortia and export trading companies, new proposals would loosen antitrust law still further. Similar concerns are expressed that US export controls unduly hamper American companies ability to sell abroad. Specific sectors, notably chemicals and related products, have been a focus of particular concern. The need to minimize regulatory uncertainty, delay, and inconsistency is an important part of the effort to enhance the commercialization of technology.

2. Effectively Organizing and Coordinating Federal Technology Programs

For most of the post-War period the Federal science and technology policy apparatus was dominated by a few institutions and sources of expertise, focused on science and large technology projects, relatively unpolitical, reasonably predictable, and largely isolated from the business community. Today, the situation is characterized by many more actors, increased politicization, perhaps less power in the technical agencies, and a broader ambit of concern.

A major issue for the Executive Branch is whether the existing organizational model, in which responsibility is diffused throughout many agencies, should be supplemented by a more centralized approach, such as a department of science and technology. A related question is whether technology and commercialization should be emphasized more through the creation of agencies that focus on this particular mandate solely rather than in combination with others.

In Congress, the budget process is a main concern. Diffusion of responsibility among authorizing, budget and appropriations committees and the Executive have led to difficulties in program consistency and implementation, as well as an increase in the tendency toward pork barrel science and technology projects.

Lastly, although the contribution of science and technology to national economic well-being is now well-recognized, few institutional mechanisms have responded to the need to integrate the business community into the policy development process.

From: Targeting the Computer: Government Support and International Competition (pp. 173-206)
by
Kenneth Flamm
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CHAPTER SIX

National Technology Policy: Past, Present, and Future

THE DEVELOPMENT of the electronic digital computer is a useful case study in the development of modern high-technology industry. The computer was born during the second world war, a product of powerful and pervasive institutional change that reshaped the American economy. It ranks among the most research-intensive goods, and development of computer technology requires complex interactions among the interests of the state, private business, and the public welfare. Determining the contours of investment in technology is one of the most important economic choices that societies make.

The computer emerged in an arena that was international in scope right from the start, where it was impossible to separate competition at home from rivalry abroad. Firmly connected to the United States' national security, economic and military, the computer was guaranteed a special status by the willingness of the military services to push its development when civil authorities seemed to lack the interest, the will, or the resources.

The Past: A Summary

At first the economic significance of computers went unnoticed; military need, not the economic imagination, propelled the technology forward. A few far-sighted visionaries saw the computer's commercial potential, but had it not been for the military's interest in powerful information processing capacity, its development would certainly have been delayed by years, perhaps even decades.

Throughout the 1950s the links between commercial and military technology remained strong. Many of the American computers built were government-financed machines adapted to the commercial marketplace. The differences between the United States and the other industrialized countries during this decade are particularly striking. The scale and scope of funding for computer development in the United States dwarfed efforts abroad. The Air Force's SAGE project alone accounted for billions of dollars in development funds, compared with tens of millions, perhaps, invested abroad. Great Britain, initially a credible technological rival to America in computers, slipped further and further behind. Close to one hundred firms entered the computer business in the United States in the 1950s compared with fewer than ten in England. When business demand for computers exploded in the early 1960s, the scientifically oriented machines built by British firms were overrun by business-oriented American computers, and the long, sad decline of the British computer industry quickened. France, Japan, and West Germany trailed far behind the United States in the infancy of computer development. They each had a few small, primitive machines not far removed from experimental research prototypes. Other European countries dropped out of the competition altogether, and their researchers staffed the first multinational laboratories, the early outposts of an increasingly internationalized industry.

The American market decisively shifted away from government customers toward commercial business users in the late 1950s. The rapid growth of the market was largely driven by technological advance: continuous, accelerated declines in the cost of computing power opened up new applications. Use of information processing machines had become economic. But the technological base from which these cost declines flowed, including electronic components, continued to benefit from a steady diet of government funding.

As the market for business computers opened wide in the early 1960s the technological lead of U.S. firms translated into solid profits. Dependence on the United States for what was becoming an essential capital good increased. U.S. export controls on shipments of high-performance computers to France dramatized that the so-called strategic argument for having an autonomous technology base was more than a thinly veiled appeal for protection of an infant industry. Interruption of the supply of products embodying state-of-the-art technology could have potentially crippling effects, not just on military preparedness, but also on the increasing number of user industries.

France, then West Germany, and then Great Britain embarked on crash programs to build up their national base in computer technology. The basic formula was generous R&D funding, government procurement preferences, and protection from foreign imports. The latter policy, as it turned out, served mainly to increase U.S. computer firms' European investments.

Analysts at the time emphasized the advantages of market size in reducing the per unit development costs for new products. Consolidating all computer production into one favored "national champion" was a popular solution. The hope was that by creating a smaller, national, "scale model" of IBM, the European markets dominated by IBM would be recaptured. It was an inward looking strategy that overlooked the economic logic for tapping into global markets in technology-intensive goods. And it was a losing strategy in Europe for precisely the same reasons that facing off with IBM in established markets was a losing strategy in the United States. Worse yet, no support was given to new entrants in a position to go after new markets in the manner that was to prove successful in the United States.

Of the European countries only West Germany reconsidered its initial strategy. This change of heart came after Nixdorf, with absolutely no help from the state, bested the performance of the chosen national champion by pioneering the European minicomputer market. This more diverse style of support has been relatively effective. Today the German computer industry is generally regarded as the strongest in Europe. Although computer research in Britain is quite highly regarded, its commercial industry remains weak. And France's two decades of protective nurture for a single national champion has had little apparent impact on its ability to prevail against its rivals in open competition.

Japan took a rather different tack. By carefully controlling access to the Japanese market, Japan's Ministry of Trade and Industry (MITI) attempted to induce U.S. computer producers to transfer computer technology to Japanese manufacturers. At the same time it promoted research and development within Japanese industry. The development of the underlying technological infrastructure took place under the technical leadership of Nippon Telephone and Telegraph (NTT) and MITI's Electrotechnical Laboratory. In the early 1970s this infrastructure was seriously shaken when many of the American firms with arranged marriages to Japanese producers dropped out of the battle for computer markets.

A new focus on support for national R&D efforts, with heavy reliance on MITI-brokered cooperative industrial research, was begun. In entirely unforeseen ways this strategy proved effective. The key development in international competition in computers in recent years has been the steady and rapid advance of Japanese computer technology. Japan now has achieved parity with the United States in many commercial products. Japan's announcement in 1981 that it intended to become a leader in frontier research areas (the oft-mentioned Fifth Generation project) prompted considerable reaction around the world.

The bold technical goals of this ambitious project reflect a shrewd assessment of economic realities. After all, if advanced parallel computers or new types of software products render existing technology truly obsolete, whole new methods of programming will be needed. Then the existing stock of software—the basis for much of IBM's advantage in global markets—will gradually be replaced. A new generation of fundamentally different types of advanced products will open up a vast new market—a market where past hegemony will provide minimal advantage.

The Role of Government

The role of government in stimulating the development of computer technology in the United States, unlike Europe and Japan, became considerably less visible during the 1960s. As the commercial market mushroomed, the general influence of government sales and R&D funding steadily declined. Nevertheless, the most sophisticated and most advanced hardware and applications continued to be funded by federal users.

The military services have always provided the bulk of government funding for U.S. computer research. For a while, the military share of computer research support declined, but the host of new military programs to sponsor computer technology announced in the early 1980s, in apparent reaction to the eroding American lead in commercial markets, suggests that this trend has been reversed. Civilian funding for computer research, particularly for applied research and engineering projects, has also increased dramatically in the United States in the last several years.

Military dominance of U.S. computer research contrasts sharply with the situation in Europe and Japan. The sources of funding have primarily been commercial even in France, where access to supercomputers needed for military research was a catalyst to the program of support for computer technology begun in the mid-1960s. In West Germany and Japan, ministries charged with supervision of industrial development and scientific research, not the military, have been the big spenders on computer development.

In the United States, spin-offs into the industrial sector have been a major objective of military support for computer technology. The promise of significant "fallout" motivated programs begun by the Defense Advanced Research Projects Agency (DARPA) in the early 1960s as well as its recent grand effort, the strategic computing program. By upgrading the technology that the military can procure from industry, the military, as a computer user, benefits. Needless to say, industry and the commercial computer user also benefit, and the social returns reaped from commercial use (which certainly overwhelm those from military use in sheer numeric terms) have probably far outweighed the gains from reduced cost and increased capabilities of military systems. In fact, technological megaprojects like the SAGE air defense system—expensive white elephants from a strictly military point of view—gave rise to important new commercial technology. They are remembered with pride and affection as great successes rather than as costly and failed attempts at buying a technological national security fix.

Attempts to quantify the extent of government involvement in financing computer research turn some popular myths about "targeting" policies on their heads. While it is true that Japanese authorities heavily subsidized computer development in the 1970s, these efforts have never approached the relative share of all R&D funds supplied by the U.S. government in the 1950s and 1960s. The proportion of computer R&D performed in MITI-organized cooperative computer research projects in the mid-1970s—the peak—was about half of the total, and only one-quarter of all funds were supplied by government. This fraction is just a little more than the share of all distinctly identifiable computer research paid for by the U.S. government in the early 1980s. Moreover, the Japanese government's relative role in financing computer research declined significantly in the late 1970s. Today government directly funds *less* of Japan's industrial computer research and development than is the case in the United States or Europe.

There are other means of supporting a research-intensive industry, and historically they have been important. In Japan during the 1960s and early 1970s, tax measures favored computer producers and users. But in the mid-1970s policy shifted to favor investment in particular technologies over other, more general subsidies to investment, and tax subsidies shrank in significance. Emphasis was redirected to research and development. Overall, there is little evidence that such tax preferences are a major factor in competitiveness today. (But one unusual, and perhaps irreproducible, feature of Japanese tax policies favoring high technology is the frequency with which incentives have been set, adjusted, and revised.) In Europe policy shifted in the opposite direction, and general subsidies to cover the losses of the ailing British and French national champions increasingly replaced the more targeted support for research and development that was typical of earlier years.

There is also little evidence that the subsidies inherent in the provision of low-cost loans from state-controlled financial institutions have been very important in recent years in Europe (with the possible exception of France's aid to Bull) or Japan. Direct support for research seems to be the targeting weapon of choice, and general subsidy the medicine of need for truly desperate financial ailments.

Procurement preferences by government users have been a powerful instrument of policy in Europe and Japan. By far the highest proportion of government markets has gone to national producers in Japan. European procurement has also favored national firms but to a lesser extent, perhaps in part because the products offered by European producers have not matched those of Japanese manufacturers in quality and breadth.

In the United States federal procurement of foreign hardware has never been much of an issue, presumably because of the superiority of American technology. But now Japanese producers are offering supercomputers that are competitive with American products (with the added fillip of some degree of compatibility with IBM machines).[1] It remains to be seen whether the United States' open procurement policies will continue. None of the new supercomputing centers sponsored by the National Science Foundation (NSF) will use Japanese equipment. The moment of truth may yet come when one of the U.S. national laboratories or universities considers buying a Japanese supercomputer.[2]

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[1] Benchmark tests run on Cray X-MP/2, Fujitsu VP-200, and Hitachi S810/20 supercomputers in 1984 and 1985 showed the Cray and Fujitsu machines roughly comparable in performance for typical workloads from the Los Alamos National Laboratory and the Hitachi machine somewhat slower. See Olaf Lubeck, James Moore, and Raul Mendez, "A Benchmark Comparison of Three Supercomputers: Fujitsu VP-200, Hitachi S810/20, and Cray X-MP/2," *Computer*, vol. 18 (December 1985), pp. 10–24.

The structural aspects of Japan's support for research, not just the billions of yen invested, explain its successful record in catching up to the United States in state-of-the-art commercial computer technology. Japan clearly pioneered the concept of joint industrial research. Together and in parallel, industry and government invest in a generic, precompetitive, technology base, which is then further developed into commercial products within individual firms. Such arrangements reduce duplication of the least appropriable elements of investment in technology, which, although critical to further progress, are not particularly rewarding to the company that shoulders their financial burden. Cooperative research also effectively shares the risk in more speculative, long-term research investments. The best testimony to the perceived success of these policies is the extent to which they have recently been imitated in the United States and Europe, in many cases as the result of private initiatives.

Perhaps the most fascinating aspect of these nations' technology policies is the cycle of action and reaction stimulated through competition in the international marketplace. Pushed by the desire to stay competitive with foreign producers, governments have repeatedly altered their policies in reaction to developments abroad. The United States' superiority in a rapidly expanding market pushed Europe and Japan to large-scale intervention in their industries in the mid-1960s.

As a direct consequence of the financial demands of the Vietnam War, the U.S. government's support for computer technology, insulated from international competition by the lead it enjoyed at the time, declined. It was the visible return on Japan's technology investments in the late

[2] C. Gordon Bell, the NSF administrator charged with oversight of its supercomputer program, recently noted that it was "NSF's intent to fund the five national centers such that they can all have the leading-edge computers manufactured by our *domestic* industry" (emphasis added). Willie Schatz, "Render unto Caesar," *Datamation*, vol. 33 (March 1, 1987), p. 22. In fact, the heavily discounted sale of an NEC supercomputer to the Houston Area Research Consortium (HARC) in March 1986 provoked a considerable outcry. And the award of a procurement contract to Honeywell, involving the sale of its largest mainframe computer model, sparked some public furor in the fall of 1986. The reason for the episode was that the Honeywell computer was actually manufactured by Japan's NEC Corp. See Richard Gibson, "Honeywell to Sell Pentagon a Computer Designed in Japan; Competitor Cries Foul," *Wall Street Journal*, October 17, 1986; and Karen Gullo and Robert Poe, "Where There's Smoke, There's Fire," *Datamation*, vol. 33 (March 1, 1987), p. 18.

1970s that awakened American industry and government from their complacent slumber. And it was the direct challenge of Japan's Fifth Generation program that provoked a massive new wave of American (and European) R&D investment in the mid-1980s.

Ironically, domination of the international marketplace is in many respects the least significant reason for a society to invest in computer technology. The social rate of return to this investment has been quite high. With rather conservative assumptions, an economic rate of return on the order of 50 to 70 percent is produced for society; more realistic assumptions would push the calculations even higher. Private returns, on the other hand, are considerably lower because of the pressures of competition from other high-tech firms and the relatively short time during which private firms have an exclusive monopoly over the fruits of their R&D investments. The social benefits of R&D investment may last forever, but the private profits produced, while sweet, are short lived.

The bulk of the social return is mainly reaped by domestic consumers in lower prices, and it far outweighs any technological rents derived from domestic and foreign sales. Yet, because foreign sales are a large portion of private revenues (typically 40 to 50 percent for U.S. firms), rents derived from foreign operations are a major source of private return on U.S. investments in computer technology. Without them, marginal projects would not be undertaken, and the pace of technological advance would slow considerably.

The Directions of Technical Advance

The economic rationale for a continuing government role in computer development is closely tied to the degree to which private firms can capture the results of R&D investments. No matter how great its payoff, basic research is more difficult to appropriate privately and therefore less likely to be undertaken by private firms. Private firms also are less likely to undertake radical innovations (as opposed to incremental advances) because much of the uncertainty in moving far beyond existing demand curves can be resolved only by actually developing and marketing a highly innovative good. Prospecting for profitable innovations on the technological frontier yields information about the nature of demand that is as easily grabbed by claim jumpers as by the risk-taking explorer.

Therefore, private firms have a considerable incentive to hold back and not hazard their own capital in removing these uncertainties.

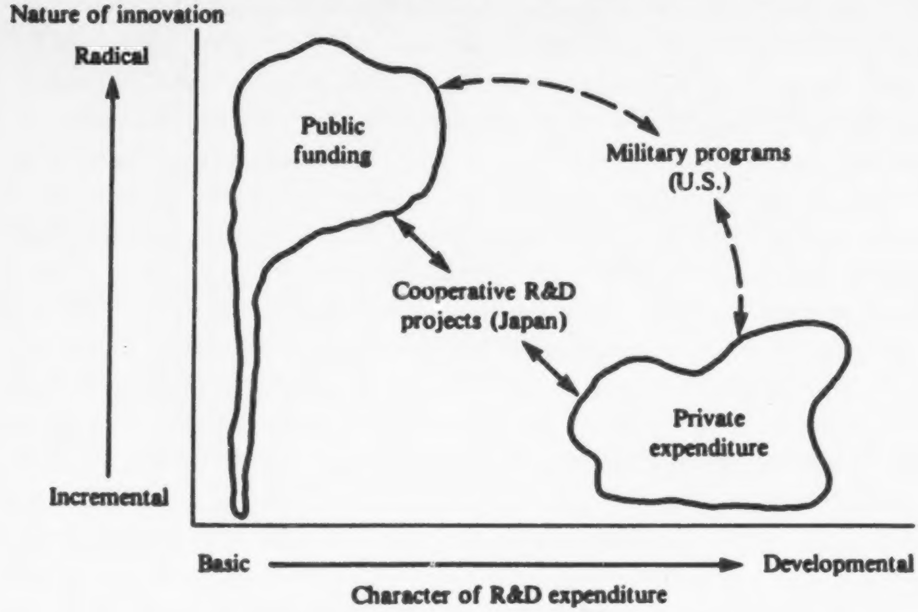
Over time government support has assumed its greatest role in exactly these two areas: the most basic research and the most radically innovative projects. In the very beginning of the computer industry, government dominated all aspects of the technology, from financing development to buying production. But as computers evolved and diverged technologically, government became more important in some aspects of technology development, much less important in others.

The growth of the U.S. market is instructive. Around 1950 the government (defense contractors included) was the only significant customer and funder of research. The technological directions that were being explored were aimed at improving all dimensions of computer performance. Around the mid-1950s small start-up firms began to deliver machines that were smaller and offered lower performance but were much, much cheaper. Their designers took established technologies and invented clever ways to cut cost without proportionate losses in performance. Government users remained the initial customer for many of these machines, but they played little direct role in their design.

In countries with less-developed computer industries, such as Japan and France, the market for smaller machines was the niche into which their early computers fit. Because of the emphasis in this market on clever designs using already developed component technologies, and on settling for lower performance, a recent entrant has some chance of becoming competitive without spending enormous amounts on research and development. U.S. government research support, on the other hand, clustered around the high-performance, large-scale, scientific end of the computer spectrum. Government users began to purchase commercial, business-oriented machines for their ordinary data processing needs, and federal support for research and development was reserved for technologies that pushed the limits of speed and size and therefore favored developments most applicable to the very largest, high-end, scientific machines.

When the commercial market began to really take off in the mid-1950s, government sales became considerably less important to U.S. vendors of small- and medium-sized scientific computers and business-oriented machines of all sizes. Government purchases rapidly shifted toward more commercial types of applications. Even before private

Figure 6-1. *Public versus Private Investments in Technology*


Nature of innovation
Radical
Incremental
Public funding
Military programs (U.S.)
Cooperative R&D projects (Japan)
Private expenditure
Basic
Developmental
Character of R&D expenditure

business, government had begun to automate and computerize its record-handling and data management functions.[3]

Thus as the U.S. industry matured, the government's role in stimulating research and sales grew quantitatively smaller. Federal research support was concentrated in leading-edge, high-performance machines. However, since the most advanced technology ultimately diffused into the mainstream of commercial computing, the impact of this support was considerably more influential than the numbers might indicate. The results of these efforts were transferred to industry through the publication of research and, more important, through the mobility of engineers. Then and now it is the most advanced, risky, and speculative technologies that benefit the most from government research expenditure.

Figure 6-1 portrays one way of viewing the distribution of potential R&D projects. On one axis, projects are sorted by the mix of R&D effort required, from most basic to most applied and developmental. On the other axis, projects are distributed by the extent of their departure from current practice, from marginal, incremental improvements on current technology to truly radical leaps into the unknown.

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[3] Government users pioneered the commercial uses of computers in the early 1950s. The first computers sold for commercial-type applications were used in the military. (UNIVAC number 2, for example, went to the Air Force in 1952, for use in inventory management and logistics applications.)

By definition, basic research is undertaken with no concrete application in mind, but rather to add to the general stock of knowledge. Ultimately, of course, basic research may influence both incremental and radical commercial innovations. The results of the most basic research might be scattered somewhat randomly along the "nature-of-innovation" axis. Applied research and development, by contrast, are focused on particular results, and the objectives of the organization undertaking the project play a much greater role in determining the outcome of the effort. For that reason, innovations resulting from applied research and development projects are depicted in this figure as clustered along particular areas of the nature-of-innovation axis that are related to the interests of the R&D sponsors.

Commercial projects tend to be concentrated in the lower right quadrant of the diagram. Conversely, public support grows proportionately more important as more basic, radical projects are considered, moving up and to the left in the diagram. The results of pure basic research will tend to be scattered along the entire nature-of-innovation axis. But, as more applied research is considered, it will be the most "far-out," radical projects unlikely to attract the interest of private sponsors where public resources will make a difference in determining whether or not the project is undertaken.

Such radical "blue sky" projects may have relatively little existing stock of trained manpower to draw upon. Whole new sets of skills and expertise may have to be created. The people who embody the fruits of this very costly investment can easily pull up stakes and migrate elsewhere. Thus in precisely the most radical, costly, and risky projects, the difficulties of capturing the payoff may be the greatest.

If one considers technology policy as a tool for joining public support for more basic research to the less radical, developmental effort most profitable for private interests, the varying character of national technology policies might be sketched in figure 6-1. In Japan the government-sponsored cooperative R&D projects are a direct bridge of sorts between upper left and lower right, between government-funded basic effort and privately sponsored development projects.

In the United States the link between government-sponsored basic research undertaken in universities and private development has been less direct. If military interests in research and development are located in the upper right quadrant (that is, the development of radical new weapons systems yielding qualitative strategic advantage), then participation by both industry and academia on such projects has provided an indirect link between the public radical/basic and private incremental/development orientations.

Public investment in the basic and radical has always been linked to private investment in development of the practical. When far-out government research projects and starry-eyed university research have begun to pan out, commercial firms have frequently "bought in" to the concepts by hiring the persons involved. On a more mundane daily basis, by recruiting graduate students trained in more exotic academic research funded out of the public coffers, commercial firms have maintained a continuous inflow of good, basic, new ideas without much of the large and relatively unprofitable (from a single firm's perspective) investment that would otherwise have been required.[4]

It is at the most daring leading edge that government research support continues to play its crucial role. These projects are too risky, too long-term, and too little of their results can be kept within the firm, for companies to be much interested in investing in them. *Basic, precompetitive, radical, long-term*—these are the adjectives that describe the types of research where public support can be most important in supporting a social investment that otherwise might not be made or made at a considerably slower rate.[5]

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[4] There is a growing body of literature on the statistical relationship between federal contract research and development performed in the private sector and both productivity and private R&D effort. Such studies have generally found small but significant direct effects on private productivity and a considerably more important indirect effect in stimulating private R&D. See David M. Levy and Nestor E. Terleckyj, "Effects of Government R&D on Private R&D Investment and Productivity: A Macroeconomic Analysis," *Bell Journal of Economics*, vol. 14 (Autumn 1983), pp. 551–61; Edwin Mansfield, "R&D and Innovation: Some Empirical Findings," in Zvi Griliches, ed., *R&D, Patents, and Productivity* (University of Chicago Press, 1984), pp. 127–48; and Zvi Griliches, "Productivity, R&D, and Basic Research at the Firm Level in the 1970s," *American Economic Review*, vol. 76 (March 1986), pp. 141–61. For an alternative analysis, see Frank R. Lichtenberg, "The Relationship Between Federal Contract R&D and Company R&D," *American Economic Review*, vol. 74 (May 1984, *Papers and Proceedings, 1983*), pp. 73–78.

[5] Several researchers have found that a general slowdown in basic industrial R&D coincided with the decline of federal R&D support in the 1970s. See, for example, Edwin Mansfield, "Basic Research and Productivity Increase in Manufacturing," *American Economic Review*, vol. 70 (December 1980), pp. 863–73; and Griliches, "Productivity, R&D, and Basic Research."

The Present: Probing the Technological Frontier

Computers are a thriving industry in the late 1980s; shipments amount to almost 1½ percent of the U.S. gross national product.[6] Sustained and continuous technological innovation explains the dynamism of this sector, and—despite a temporary setback dealt by the economic slowdown of the mid-1980s—continued long-term growth near historical rates is probable well into the indefinite future.

Amid this prosperity and growth, are government policies to support innovation superfluous? After all, the U.S. computer industry is constantly turning out new and more powerful products. Why should government fund research and development when the competitive pressures in private industry already seem so effective in generating this constant stream of innovation?

The answer is not simple. American industry certainly continues to be effective in introducing new, technology-based products. Much of this innovation, however, takes the form of marginal, incremental improvements on established technologies. The fundamental aspects of a bread-and-butter business computer of 1985 were not terribly different from the designs of 1965. Some marginal architectural improvements were made, and enormous improvements in component cost and performance were achieved, but essentially the designs represent a much improved embodiment of concepts that have been floating around for decades. When one looks carefully at the most radical, truly revolutionary concepts that are still quite experimental in nature and just beginning to come to market, a rather different impression emerges.

"New wave" computer products include high-speed communications networks linking multiple computers (or even multiple processors within a single computer), systems and languages using artificial intelligence (AI) concepts, special computers designed to run this AI programming efficiently, and ever more powerful supercomputers. All these products draw heavily on a continuing legacy of government-funded research support, and many of the first commercial sales continue to be made to government users.

A November 1986 advertisement by Texas Instruments (TI) in *Scientific American* makes this linkage explicit:

> At the heart of Knowledge Technologies [Texas Instruments' new

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[6] See table 2-2.

> line of high-performance AI computers] lies the development of a pioneering semiconductor chip. We developed it under contract to the U.S. Government for use in aerospace and defense, but its impact will be felt in all areas. One of its first commercial applications will be to enhance the power and performance of the TI Explorer computer, already one of the world's most advanced AI development tools. Also, it will add new members to the Explorer family of products.[7]

Even today, public support primes the pump of tomorrow's commercial technology.

Issues for a National Technology Policy

Currently economic theory does not go much beyond explaining why public policies to increase investments in some types of research (particularly long-term, basic research) might be socially useful. Empirical studies (including this one) have repeatedly suggested that fairly dramatic underinvestment in R&D is often the outcome of laissez faire. In many respects, it is not very useful to debate this point. Economic, political, and social forces have made government support for high technology a given of the political economy of an advanced industrial country in the late twentieth century. Discussion, then, must necessarily focus on the details of how governments support technology.

FOCUSED SUPPORT FOR RESEARCH. The economic arguments for public support for R&D primarily revolve around three issues: the inability of firms to totally capture all returns on technology investments, economies of scale in the use of new technology and their consequences, and the difficulties of capital markets in dealing with very risky and costly projects.[8] Policies to correct the imperfections of real-world markets should address the concrete details of these three problems. If the purpose of public support for research and development is to ensure that socially worthwhile R&D investments are made that otherwise might not be, then public resources should be directed to the areas where appropriability problems are greatest (that is, basic, high-risk research and radically innovative, leading-edge projects).

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[7] Advertisement run in *Scientific American*, vol. 255 (November 1986). Other key elements of the Explorer computer's design are licensed from MIT, where they were developed with DARPA support.

[8] One such difficulty involves the issue of moral hazard, first raised in Arrow's classic 1962 article. Kenneth J. Arrow, "Economic Welfare and the Allocation of Resources for Invention," in National Bureau of Economic Research, *The Rate and Direction of Inventive Activity: Economic and Social Factors* (Princeton University Press, 1962). If an inventor is able to completely shift the risk of an R&D project by selling all the equity in his venture in competitive capital markets, he will also shed the incentive to perform the R&D in the most efficient possible fashion. On the other hand, if constrained to retain some minimum equity share in the venture, suboptimal allocation of capital may result.

Such considerations argue against using an R&D tax credit as the sole instrument of a technology policy. The strength of the R&D tax credit is that it marries market forces to public tax expenditures. But this strength is also a weakness since an objective of public support ought to be to direct resources into worthwhile areas that the market does not find privately profitable. The R&D tax credit is a relatively blunt instrument. It tends to produce overinvestment (from the social viewpoint) in projects where returns are most easily captured and continued underinvestment in projects that are most difficult to appropriate privately.[9] Sufficient resources can be directed into the hard-to-capture areas only by vastly overinvesting in easily captured research and development, if a tax credit were to be used as the sole instrument of policy.

This is not to say that some R&D tax credit may not be valuable. For most kinds of R&D—basic, applied, and development—there is a general tendency for social return to exceed private return. Some level of tax credit is a useful measure to correct for this fact. But a tax subsidy can direct resources into the areas with large differences between private

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[9] This argument is easily made in a more rigorous fashion. Let the total social return to development expenditures, E_D, be given by $R_D\,(E_D)$; the social return to basic research be given by $R_B\,(E_B)$. Let the per unit cost of R&D effort be r. Also, let R'_D, $R'_B > 0$; R''_D, $R''_B < 0$ (diminishing marginal returns to R&D effort). It is assumed that fraction c_D of the social return to development investment cannot be captured privately, fraction c_B of basic research, and that $1 \geq c_B > c_D \geq 0$. Let a rate of subsidy of s be granted to all private R&D expenditure. Then profit maximization implies investment in R&D up to the point where

$$R'_D = \frac{(1-s)}{(1-c_D)}r \quad \text{and} \quad R'_B = \frac{(1-s)}{(1-c_B)}r.$$

Social optimality argues for sufficient investment such that the left-hand side, in both cases, is equated to r. Thus, because c_D and c_B are different, setting s such that just the right amount of D takes place implies continued underinvestment in B, while sufficient B is undertaken at the cost of excessive D. If c_D and c_B are very different (that is, c_D close to 0 and c_B close to 1), the problem will be especially great. In principle, different values of s could be applied to the two categories of expenditure, but this would be impractical given the impossibility of defining or enforcing a rigorous separation between research and development.

and social returns—particularly basic and risky, far-out projects—only by pulling far too many resources into the easy, already profitable types of projects. Public policy ought to be designed to favor research in general, as well as those specific types and areas of R&D activity where both the payoff and the obstacles to private capture of that return seem greatest.

The large social rate of return reaped from all U.S. investments in computer technology, while not unheard of, appears to be greater than the returns available in certain other sectors. Because there is no market mechanism that necessarily directs resources into research areas with the greatest social returns and because social return on investment in a technology may be quite different from private return, large disparities between the social returns on alternative research expenditures may exist. Therefore, some form of targeting is inevitable when actions are based on assessments of relative social return. Those with government research dollars to dispense well realize that they are charged with putting that money where, in their judgment, it will do the most good. Their professional assessment is what plays a key role in approving projects. In practice, targeting decisions of sorts are made routinely on a daily basis.

THE COOPERATION-COMPETITION MIX. An effective technology policy may seek to encourage a mixture of cooperation and competition among private firms and between industry and academia. By encouraging cooperation on the least appropriable, basic elements of technology, more long-range research with a potential broad economic impact on industry may be undertaken. Joint research involving industry and universities can focus on commercially important (but difficult to capture for private advantage) themes that firms would otherwise neglect.

Yet a competitive market has always been essential in increasing the pace of computer innovation. A sheltered monopoly has less incentive to innovate than a firm feeling the hot breath of competition on its neck. The best evidence of the desirability of maintaining a competitive market for downstream products, even when firms share considerable research, is the history of otherwise superficially similar technology policies in Europe and Japan.

MULTIPLE SOURCES OF R&D SUPPORT. Diversity in funding sources and in research has a positive value. The history of support for technology in the United States and Japan, where different supporters of high technology have pursued distinctly different research agendas, is one of good and not-so-good decisions being made by each group. In the United States if one group had been the supreme arbiter of research policy, ENIAC, UNIVAC (universal automatic computer), Whirlwind, and other significant technology projects might never have been undertaken. Even within a single large and closely managed organization like IBM, various forms of competition in research have been carefully used to reduce the probability that any single erroneous decision will have a lasting impact on the fortunes of the organization. Because research is such a small part of the total expenditure required to develop a new product, funding multiple approaches in the research stage is a cheap way to reduce the risks involved in innovation.

MILITARY VERSUS CIVILIAN CONTROL OF RESEARCH INVESTMENT. After the first great wave of investment in technology during World War II, voices within the U.S. government argued for continuing federal support for technology but with a focus on helping industry to develop useful commercial applications. For a brief time the experiment flourished: the first fully operational computer in the United States came out of this effort.

At the time the economic arguments for investing public resources in technology had yet to be articulated. Scarcely a glimmer of the full glory of the harvest to be reaped from the unprecedented wartime effort was then visible. To powerful critics, this experiment represented a needless meddling with market forces. The effort was publicly crushed, and since then—except for basic research in universities and health research—federal support for technology has had to be justified in terms of some well-defined mission of the federal government. Defense, a cure for cancer, and putting a man on the moon are objectives deemed appropriate by Uncle Sam. But helping to build the technological infrastructure needed for a competitive American industry has not traditionally been on his list.

Since the mid-1950s, the only politically acceptable way to support the technological development of U.S. industry has been to declare it militarily strategic. Rather intricate contortions have sometimes been required to justify military expenditures that are fundamentally intended to build up the general level of industrial and scientific capacity in the U.S. economy. Unfortunately, such "frills" are often among the first casualties during military budget cutting. From the perspective of military planners, technology investments, like other items in the defense budget, are judged in terms of concrete, deliverable results and performance. The general benefits to the economy are counted only insofar as they show up in the cost and performance of other military budget items. Thus for the military, like private industry, the widespread diffusion of new technology into industry is best enjoyed if someone else's technology dollar has paid for the show.

Cyclically, almost predictably, years of budget plenty end and lean years begin. Ax in hand, military cost cutters go after items of least immediate operational relevance, and military-sponsored research programs defensively must show near-term results. DARPA, for example, has weathered several of these cycles: tolerance for visionary research projects with only indirect military relevance has been followed by budgetary distress and renewed emphasis on immediate applications, engineering, and working hardware.

Pressures to focus defense R&D on specific military missions are a constant of the political process. Even today, when economic competition with Japan is high on the agenda of projects like DARPA's strategic computing program, military research expenditure is constantly forced to define itself in terms of concrete military applications. Strategic computing, for example, must channel a significant portion of its funds to traditional military contractors, and evidence of production of concrete military applications—deliverables—must be presented to justify continued funding. For DARPA the pendulum has swung back toward applications and development.[10] These constraints in all likelihood make for a less effective policy in support of the long-term, industrial technology base.

Even in good times it is not always clear that the talk of "fallout" and economic benefits is well founded. The problem with using such appeals to justify military investments is that they cloud the issues on which judgments are to be made. If the investment were justifiable on purely military grounds, no such appeal would be required. If it were justifiable on purely economic grounds, then a rationale replete with numbers and bottom lines would have to be constructed. By moving in the no-man's-land between strategic and economic benefit, a project can slip past the snares of both economists and tough-minded generals.

Is there any way to evaluate the effectiveness of a policy that explicitly seeks out technology with long-range commercial value (rather than relying on the incidental spillover from military projects) in giving American industry a competitive edge? This is the heart of the matter, and unfortunately there are no easy answers.

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[10] See Tim Carrington, "Pentagon's Research Agency Will Shift Emphasis to Building Arms Prototypes," *Wall Street Journal*, September 16, 1986; and George Leopold, "Will Shifts at DARPA Weaken Basic Research?" *Electronics*, December 9, 1985, p. 47.

One of the continuing preoccupations of scholars studying the relationships between research and development activity and technological advance has been to characterize the differential effects of different types of R&D activity on productivity and innovation. There have been two broad types of studies—*statistical analyses,* which examine correlations between different categories of expenditure and measures of innovation, given some assumed web of causation; and *case studies,* which attempt to trace the links between particular advances and the concrete research programs from which they resulted.

Each type of study has major limitations. The statistical studies have been hampered by the limited amount, poor quality, and high level of aggregation of data on research and development expenditure. If all the major linkages among the different types of R&D expenditure, product sales, and innovation were examined, a very detailed breakdown of research funded as well as performed by government, industry, and universities would be needed. The segmentation of research and development by funders reflects the fact that a funder's objectives in all likelihood influence the outcome of an R&D project. Because of economically significant differences in private appropriability, research and development probably should be broken down further into basic, applied, and development expenditure. But because of limited data, even the best statistical studies rarely attempt to do more than disaggregate between basic research and applied and development activity or, as an alternative, between all privately and publicly financed research and development within industry.

University-based research is generally not even considered when studies unravel these relationships within industry, although—as the development of computer technology makes strikingly clear—major outputs from government-funded R&D programs have repeatedly been transferred from universities to industry with few dollars changing hands and little in the way of a paper trail. A 1986 study of industrial research and development that distinguishes between military and nonmilitary funding roils these troubled waters more. Frank Lichtenberg argues that military R&D expenditures, by stimulating contract-seeking research and development on the part of private firms expecting future procurement contracts, substantially undercount the true magnitude of resources drawn into the military R&D effort.[11]

A broad survey of the origins of key elements of computer hardware reveals significant links between major concepts and pioneering government-supported projects. The innovations cover a variety of technical areas. Many important companies repeatedly declined even subsidized opportunities to explore these new technologies in the early years, and if the federal government had not stepped in, private interest alone would certainly have generated much slower development of the technology.

Spinoffs from military computer projects continue to have a profound impact on the development of commercial computer technology. But it is far from clear that channeling such funding through military programs maximizes commercial spinoffs. Funneling R&D funding through military sponsors may even impede commercial applications in some respects. For example, compilations of patent statistics show that research and development connected to military sponsors yields considerably fewer patents of commercial interest than do equivalent expenditures by other government agencies.[12]

The Case for Civilian Objectives

A highly trained and motivated civilian agency, if given the mandate of cooperating with American industry and academia to improve the long-term technological future of the American economy, ought to be able to get at least as big a commercial bang for the federal research buck as a Pentagon planner looking for an economic hook to pull in additional support for a new weapons system. If the streamlined efficiency of defense programs was an unassailable article of faith, Pentagon budget administrators might be the best that could be, and the secondary importance of commercial objectives to many such projects might be offset by the superior performance of Defense Department administrators on technology investments. But this is not the case.

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[11] Frank R. Lichtenberg, "Private Investment in R&D to Signal Ability to Perform Government Contracts" (draft, Columbia University, Graduate School of Business, 1986). See also Mansfield, "Basic Research and Productivity Increase in Manufacturing"; Griliches, "Productivity, R&D, and Basic Research"; and E. Wolff and M. I. Nadiri, "Interindustry Effects and the Return to R and D in Manufacturing," 1984, and "Linkage Structure and Research and Development," 1984, as cited in M. Ishaq Nadiri, "Economics of R and D Investment," *NBER Reporter* (Summer 1985).

[12] In 1976 only 1 percent of the unexpired patents owned and available for licensing from the Air Force were actually licensed, as were 1 percent for the Navy, 3 percent for the Army, and 4 percent for NASA. This compared with 11 percent for the Energy Research and Development Administration (now the Energy Department), 13 percent for Interior, 15 percent for Commerce, 10 percent for Agriculture, and 23 percent for the Department of Health, Education, and Welfare. See Federal Council for Science and Technology, *Report on Government Patent Policy, Combined December 31, 1973, through September 30, 1976* (Government Printing Office, 1976), pp. 440–41.

However, since the practice of Defense and NASA has generally been to grant to contractors patent rights when requested, this may merely mean that the best inventions are harvested by contractors, leaving the chaff for the government sponsor. This is consistent with the fact that the Army and NASA, which show higher percentages of their patents actually licensed, give away their rights somewhat less frequently. See chapter 4.

Support for industrial technology ought to be decoupled from a volatile military budget. Military perceptions of the size and nature of the external military threat change. The needs of American industry do not necessarily march in harmony with the rhythm of international military competition. Military objectives, like commercial objectives, revolve around concrete goals, like delivering weapons systems on schedule, on target, and on budget. Inevitably, the long-term, the basic, the not immediately tangible are given short shrift when funding shrinks and purely military objectives are used for triage among wounded programs.

Moreover, military and commercial objectives can conflict. Research on weapons systems, by nature, imposes a curtain of secrecy over developments that might have beneficial consequences for industry if widely diffused. During the 1940s and 1950s, scientists running military programs actively worked to propagate the new technology as widely as possible among American industry. This played a major role in the rapid development of American industrial muscle in computers. Conversely, more recent attempts to control the export of information across national boundaries may directly limit the distribution and application of useful results within those boundaries.

On occasion, control can prove indirectly counterproductive to economic interest. America's attempt to deny the French nuclear program access to a supercomputer in the mid-1960s (a futile attempt) sparked crash development programs and ultimately reduced American computer sales in foreign markets in later years.

Important military systems requirements may sometimes have small commercial value. Resistance to radiation and electromagnetic pulse, for example, yield a relatively small return in commercial markets but are a central focus in products aimed at military markets.

Military specifications and test procedures sometimes drive technology in the wrong direction—that is, away from the most important commercial markets. For many years military testing and "burn-in" requirements may have been an obstacle to adoption of statistical quality-control techniques in the American electronics industry.[13] Military testing requirements for electronics packages emphasize extreme and rapid changes in temperature—relevant perhaps to aircraft, but not normally encountered in most natural environments. On the other hand, the test most relevant to commercial products—simulating the stress of switching power on and off—is not included in military specifications.[14]

The American armed forces have strongly supported research on manufacturing technology. They generally fund programs that reduce the cost of military weapons systems, which, like other highly specialized capital goods, are usually produced in small lots or batches. They have not focused on reducing costs in large-scale mass production, as is typical in consumer markets. Some have argued that similar focus has affected the type of semiconductor research supported by military programs and has made such spending less useful to commercial industry.[15]

Finally, government subsidy to industrial computer research (which largely comes out of U.S. military budgets) is distributed in a highly uneven fashion. The firms that receive assistance are not always the ones most able to successfully introduce new innovations commercially. DARPA funding for the strategic computing program, for example, has departed from past practice and placed a heavy emphasis on supporting research in the large, specialized defense systems contractors. These firms, had they the inclination, may not have the ability to rapidly commercialize new technology in the marketplace. The skills needed to compete effectively in the military market may be quite different from the ones needed to succeed in the commercial market, and programs that channel research resources to more heavily defense-oriented contractors may yield proportionately less commercial return.

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[13] See Kenneth Flamm, "Internationalization in the Semiconductor Industry," in Joseph Grunwald and Kenneth Flamm, *The Global Factory: Foreign Assembly in International Trade* (Brookings, 1985), p. 122.

[14] Tobias Naegele, "Englemeier: 'Mil Specs Drive People in the Wrong Direction,' " *Electronics*, October 28, 1985, p. 57.

[15] The case is made in Leslie Brueckner with Michael Borrus, "Assessing the Commercial Impact of the VHSIC (Very High Speed Integrated Circuit) Program," Roundtable on the International Economy (University of California at Berkeley, 1984); and Jay Stowsky, "Competing with the Pentagon," *World Policy Journal*, vol. 3 (Fall 1986), pp. 697–72. The semiconductor manufacturer Intel is reported to have opposed VHSIC on similar grounds. Glen R. Fong, "The Potential for Industrial Policy: Lessons from the Very High Speed Integrated Circuit Program," *Journal of Policy Analysis and Management*, vol. 5 (Winter 1986), p. 277.

A Missing Link

Outside of the military research agencies (and, to a lesser extent, the National Aeronautics and Space Administration and the Department of Energy), the government organization that spends the most research cash in the national interest has been the National Science Foundation. Recently the NSF has shifted a larger share of its budget into more applied, engineering programs with a distinct emphasis on cooperation with industry. This shift clearly reflects its (and the government's) growing preoccupation with maintaining industrial competitiveness in an increasingly challenging international marketplace.

Supporting industrial technology, however, is not what the NSF was set up to do. Its first and most outspoken proponent, Vannevar Bush, believed that basic research divorced from the immediate needs of commercial industry was the essential foundation for applied forms of technological progress. This conviction prompted his call for the establishment of the NSF. Forging direct links between university research and applied industrial objectives is far from the foundation's original charter of supporting basic scientific knowledge, unfettered by any requirement that it show industrial relevance. To quote Bush, "basic research is essentially noncommercial in nature. It will not receive the attention it requires if left to industry."[16] The whole decisionmaking structure of the NSF was set up around academics making judgments about the academic research projects of their peers based purely on scientific merit: profitability and potential industrial application were of secondary concern if any.

In the late 1960s the NSF began to edge toward other priorities. Applying technology to solve social problems emerged as an objective appropriate to the times, and Congress in 1968 amended the NSF's charter to include applied research among the agency's concerns. Much of this thrust fizzled out in the late 1970s.[17] By the 1980s the challenge of newly felt international competition sparked a new emphasis on economic relevance, and the shift began toward engineering, particularly the NSF's Engineering Research Center program, which has been the focus for recent growth in agency funding.

A wholesale shift in NSF priorities toward applied research, engineering, and advanced development projects represents a major change in course for the NSF. If one agrees with Bush that basic research deserves its own organization, then NSF's new focus on industrial technology fills one space by emptying another. Judging what areas of applied industrial research merit long-term support is a very different type of judgment—in part an economic one—than the pure consideration of intellectual merit around which NSF procedures are organized.

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[16] Vannevar Bush, *Science: The Endless Frontier,* Report to the President on a Program for Postwar Scientific Research (GPO, 1945), p. 17.

[17] See NSF Advisory Committee on Merit Review, *Final Report,* NSF 86-93 (Washington: NSF, 1986), pp. 11–12.

A vacuum now surrounds an important social purpose: to support applied research and early development of the new technologies required to keep America's industries economically fit. The industrial technology base is no one agency's explicit target. All responsible public servants in the various research-funding bodies, of course, realize that the technology base is a fundamental national interest, even if it is not explicitly written down in the *Federal Handbook*. So the missions and charters of the various agencies are stretched whenever a particularly worthwhile investment comes along.

The Future: New Technology for American Industry

How can national policy better serve the common national interest in expanding and improving American society's investment in technology? For decades this question was rarely asked. The United States' lead with respect to other countries' technologies was so great, its economic muscle so strong, that the unforeseen fallout from its huge investments in military R&D was quite sufficient to keep the nation's industrial technology second to none. Today, however, competitors have caught up to the United States in important areas and may even have passed it in others. They are investing sums comparable in magnitude to U.S. military R&D programs in commercially oriented research ventures.

As chapter 2 made clear, public investments in computer technology are justifiable on purely economic grounds. The wisest investments are in the most basic research and high-risk, radically innovative projects. To plant technological seed corn that industry can harvest later, the areas of research with the greatest commercial and industrial potential should be selected. And the selection mechanism should be workable in the institutional context of American industry.

What is the simplest national policy to achieve these objectives? It is to use public resources to partially offset the costs of joint industrial investment in basic and "generic" technology development. The policy is clearly workable. Concerns about increased international competition have already prompted American business to form cooperative, joint research associations in unprecedented numbers. Today support for joint, precompetitive, generic R&D is quite widespread. Influential figures within even that most entrepreneurial of American high-technology sectors, the beleaguered American semiconductor industry, are now calling for a massive new cooperative research program to tackle the technological roots of its current distress.[18] With little publicity, powerful bureaucrats are taking steps on their own to fund such programs.[19] Never has the moment seemed better to explore a new direction, an experiment in policy, and never have the stakes seemed higher.

Underwriting some portion of these ventures with federal funds or tax expenditures would pull more resources into the applied research and generic technology development undertaken by these organizations, as well as raise the overall level of R&D investment. Moreover, such a policy would guide public funds into areas that industry believes to be productive, but where the benefits are difficult to capture and individual, private efforts therefore unlikely to succeed.

If, say, 40 percent of the investment is offset through the tax system or direct funding, firms will still be providing the remaining 60 percent of the funding by risking their own resources. The resources so invested will then be funneled to the projects thought to have the highest payoff for the industry as a whole. A funding mechanism that shares costs and risks creates built-in incentives for allocating resources efficiently.

And, of course, jointly pooled resources will be directed into precisely those areas—basic, and generic, precompetitive research—that are least likely to be appropriated (and hence funded) by individual firms. Perhaps the most eloquent testimony to the effectiveness of these arrangements is the extent to which their use grew in Japan, where they were first devised and tested, and is now being emulated in Europe and the United States.

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[18] See "Editor's Overview," and Harvey Brooks, "National Science Policy and Technology Innovation," in Ralph Landau and Nathan Rosenberg, eds., *The Positive Sun Strategy: Harnessing Technology for Economic Growth* (National Academy Press, 1986), pp. 15, 156–57; and Richard R. Nelson, *High-Technology Policies: A Five-Nation Comparison*, American Enterprise Institute Studies in Economic Policy (Washington, D.C.: AEI, 1984), p. 73. See also Richard Bambrick, "Sematech Gets SIA Go-Ahead; Target Gov't, Ind. for Funds," *Electronic News*, November 24, 1986.

[19] Administrators in the Department of Defense and the National Science Foundation, for example, recently budgeted contributions of $1.1 and $0.1 million dollars respectively to the nonprofit Semiconductor Research Corporation for precisely these reasons.

The institutional mechanisms required to establish such a program, in some sense, already exist. The Stevenson-Wydler Technology Innovation Act of 1980 called for the establishment of a cooperative generic technology program, new organizations within the executive branch to study and stimulate the development of technology applicable to industrial needs, and the organization of centers for the development of industrial technology at universities and other nonprofit institutions. The Commerce Department was empowered to fund up to three-quarters of project costs at the centers for industrial technology, which were eventually intended to become self-supporting.[20]

The Commerce Department, however, never implemented most of the provisions of this law. This was a political decision. But the fragmented and sprawling bureaucracy of the Commerce Department may not be the best organization to implement such a program. It already wears too many hats: protector of declining American industries, champion for small business, forecaster of the weather, compiler of economic and demographic statistics, promoter of American exports, registrar of patents, traffic cop for the radio spectrum, extoller of the virtues of tourism in the United States. Although the Commerce Department does have isolated centers of technological expertise—particularly the National Bureau of Standards—overall it has not displayed a solid understanding of, or informed interest in, important technological issues. A more effective steward of America's technological edge in world markets might be a smaller, totally dedicated organization.

The National Technology Office

The purpose of this National Technology Office (NTO) would be to monitor the international competitiveness of American products both on the market and under development, report on its observations for public debate, facilitate the formation of joint research ventures within American industry, and serve as custodian of the public interest in those associations formed to carry out joint industrial research. The organization might resemble a civilian DARPA, charged with stimulating long-term investment in key industrial technologies. The private sector could define areas for investment by forming joint research associations with particular objectives and then seeking partial federal financial support. The role of the NTO would be to approve the bona fides of the group seeking partial support—something like approving the tax exemption of a nonprofit organization—and to certify that the project involved the kind of activity that the program was intended to assist—namely, generic, precommercial technology development.

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[20] See Office of Technology Assessment, *Information Technology R&D: Critical Trends and Issues* (Washington, D.C.: OTA, 1985), pp. 32–33; and J. A. Alic, "The Federal Role in Commercial Technology Development," *Technovation*, vol. 4 (1986), pp. 266–67.

The precise method of backing private investments, be it tax credits for eligible R&D or direct grants in important but imperfectly appropriable technology projects, is less important than the principle. Business and society must be partners if needed investment in America's future are to be made. They must share the risks and rewards of their long-term technology investments. Each must contribute if they are to jointly prosper.

As a clearinghouse for joint research, the NTO could eliminate obvious duplication and aid the flow of nonproprietary information within industry and between industry and academia. And it would be in an invaluable position to mobilize American industry in the face of new technological challenges. It could constantly scan the technological horizon, identify important new developments, sound the alarm, or propose an initiative when necessary. And it would safeguard the public interest in the collusive arrangements that cooperative research must, by definition, involve. Joint industrial research programs generally require some form of antitrust exemption. The National Technology Office might offer cooperatives antitrust relief, in addition to partial matching of funding on eligible projects, as a quid pro quo for a public representative (perhaps drawn from its ranks) on their boards to keep an eye on the public interest. That interest would include the responsible expenditure of public funds and the guarantee of adequate downstream competition in products developed privately using this research base. To ensure equality of opportunity and absence of political bias, such ventures would be open on equal terms to all firms willing to meet whatever transparent and nondiscriminatory financial and participatory requirements were established.

Setting up the NTO would require skilled personnel able to develop useful working relationships with industry. Technically knowledgeable specialists would mix with economic and financial analysts within the organization. To keep its technical skills at the cutting edge of innovation, it might have an internal research capacity, not unlike MITI's relationship with its internal industrial science laboratories.

Fortunately, there already exists within the federal government a small but competent band of technical specialists that has extensive experience working with industry on joint research projects. That group, of course, is the National Bureau of Standards, the same NBS that back in the 1950s built the first fully operational stored program computer in the United States. Today it is deeply involved in applied research on manufacturing technologies, computers, and robotics.

Standards issues are reshaping commercial markets and technology. With General Motors, the NBS is testing an architecture for future automated manufacturing systems as part of the program to develop the Manufacturing Automation Protocol (MAP). With the cooperation of other firms, the NBS is working on computerized manufacturing and design standards such as the integrated graphics exchange standard (IGES) and the product data definition interchange (PDDI) standard. In addition, it is doing work under contract to DARPA as part of the strategic computing program.[21]

One simple solution, then, would be to take part of the technical core of the NBS, transplant it to a new organization, and greatly expand the scope of the work those specialists currently direct. This technical staff and trained economic and financial analysts would make up a small hybrid organization—something like a cross between the current NBS, Arthur D. Little, the Congressional Budget Office, and the Office of Technology Assessment. The charter of the new organization would be to monitor the technological health of American industry, keep abreast of developments abroad, issue periodic reports, and formulate long-range proposals for accelerating the advanced research and development needed to maintain the quality of America's industrial technology base.

The President's Commission on Industrial Competitiveness released a report in 1985 that advocated more radical changes. It favored the creation of a "superagency" to preside as czar over *all* nonmilitary research.[22] The National Technology Office, however, would have as its only concern the state of American industrial technology. Although the only group in government with this specific charge, it would be one of many influences in the government's research policy community. The NTO would supplement, not replace, the voices of DARPA, the NSF, and NASA. These agencies could get back to performing the missions for which they were designed. No longer would they be involved in the contorted justifications required to deal with unmet social needs outside their charters.

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[21] NBS is doing research on speech coarticulation as part of the speech understanding segment of the program. See Defense Advanced Research Projects Agency, *Strategic Computing: First Annual Report* (Arlington, VA.: DARPA, 1985), p. 9.

[22] See President's Commission on Industrial Competitiveness, *Global Competition: The New Reality*, vol. 1: *Report of the President's Commission on Industrial Competitiveness* (GPO, 1985), pp. 22–23, 51.

How might the NTO mobilize the collective efforts of American industry in the face of technological challenges from abroad? The following scenario describes one set of circumstances in which the NTO might function as a catalytic agent for joint industrial research.

Synchrotrons and Other Developments

The NTO might play a vital role in the development of high-intensity X-ray lithography apparatus to etch microelectronic devices with very fine, dense features. Such devices are essential for future generations of high-performance semiconductors in general, and computer circuitry in particular. The technology is still experimental, and a practical system awaits the development of a compact, superconducting, synchrotron storage ring. (Developing this equipment might dovetail nicely with applied research on newly discovered superconducting materials.) This equipment, once developed, may be quite expensive—perhaps $10 million for a synchrotron X-ray source and the capacity to etch six to ten semiconductor wafers at once.[23] Although most semiconductor and computer firms are interested in the technology, few can afford to risk the large investments required by such a costly and highly speculative project.

As of mid-1986 this technology was being explored on a large scale with government support in West Germany and Japan but not in the United States.[24] IBM has been cooperating with the Brookhaven National Laboratories of the Department of Energy in the development of a synchrotron-based etching system, but this appears to be a modest effort falling well short of the large investment required to develop a practical prototype machine.

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[23] The cost estimate was given in a presentation by Peter Rose of the Eaton Corporation at the National Research Council Seminar on "Advanced Processing of Electronic Materials in the United States and Japan: A State of the Art Review and Its Policy Implications," Washington, D.C., June 4, 1986.

[24] See National Research Council, *State of the Art Reviews: Advanced Processing of Electronic Materials in the United States and Japan* (Washington, D.C.: National Academy Press, 1986), p. 24.

In the summer of 1986 MITI formed a cooperative research venture company, K. K. Sortec, to develop compact, synchrotron-based X-ray etching systems. This effort was part of the Japan Key Technology Center, a new organization founded in the fall of 1985 and authorized to fund up to 70 percent of the cost of private research ventures. Seventy percent of the funding for the ten-year venture, with a budget now pushing $5 million, is coming from the government, the remainder from a consortium of thirteen Japanese firms.[25] Another synchrotron project is under way within NTT.

Many U.S. electronics specialists (including those of the National Research Council) believe synchrotrons merit further exploration, but no major private venture in this costly and speculative area had been announced in the United States as of early spring 1987. An alert, disciplined, and well-motivated organization like the NTO—even with less government support (say a 30 percent share)—could quickly take the lead in mobilizing U.S. firms in ventures similar to those of the Japanese.

Other areas where support for joint industrial research might improve the competitiveness of American industry abound. In early 1987 American electronics producers appealed to the government for support for a joint venture to develop advanced semiconductor manufacturing technology. This is another logical entry point for an NTO-type program. Why not have industry organize a Stevenson-Wydler-style joint venture to direct such an R&D effort, with perhaps half of the expense shared with the federal government? Industry, rather than Pentagon planners, could select the most commercially promising areas and direct its collective efforts there.

Other frontier technologies that might usefully be explored in this fashion for the collective benefit of American high-tech industry include new and exotic materials (high-temperature superconductors, ceramics, diamond films), optical switches and transmission, experimental software production systems, and molecular engineering methods. The ultimate authority on the wisdom of particular choices would be American industry. It would have its own cash at risk—a powerful incentive to choose what will prove the most commercially successful.

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[25] The companies include computer producers NEC, Hitachi, and Fujitsu. Other members are Matsushita, Mitsubishi, Sanyo, Sharp, Sony, Oki Electric, Sumitomo, Toshiba, Nikon, and Canon. See Charles L. Cohen, "Japan Kicks Off X-Ray Fab Project," *Electronics*, August 7, 1986, p. 44.

In the final analysis the question may be whether the United States is willing to change the way it does research. For forty years it has avoided difficult questions about the role of government in the development of technology by relying on the military services as the custodians of the nation's economic future. The military option is workable within the context of U.S. institutions, but it fails the other tests of a good technology policy. The cyclical feast and famine of the military budget process inevitably directs research and development away from long-term projects of only indirect military interest when the crunch eventually comes. Worse yet, economic judgments about long-term commercial promise are not part of these budget choices. In fact, appeals to commercial fallout are generally the sign of a military project that cannot be justified on its security merits, just as appeals to defense applications are the sure sign of a commercial project that isn't making it as a business proposition. We are left with a muddle—too little accountability and too much pork barrel.

The military option kept the United States moving along nicely in an era when it was the king of a one-lane road, but it needs revision as the country turns onto a four-lane superhighway crowded with other drivers jockeying for position. Panels of respected American scientists and engineers have recently published a virtual blizzard of reports that warn of dangers on the technological frontier in a number of important areas.[26]

Opening Markets in High-Technology Products

To meet the challenge of the competitive international environment, the United States must keep open global markets for its technology-intensive products. This should be the country's first priority. The protectionist backlash that is unleashed in the United States by foreign targeting policies, and more blatant moves around the world to favor national firms in national markets for advanced products, is a shortsighted reaction that works against the United States' long-term objectives. A recent trend toward erecting protectionist barriers around high-technology sectors in the United States (in semiconductors and advanced machine tools, for example) may work against the long-term interests of American high tech by setting dangerous precedents for the nation's trading partners and competitors.

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[26] National Academy of Sciences, National Research Council, *High-Technology Ceramics in Japan* (Washington, D.C.: National Academy Press, 1984); J. Nevins and others, *JTECH Panel Report on Mechatronics in Japan* (La Jolla, Calif.: Science Applications International Corporation, 1985); H. Wieder and others, *JTECH Panel Report on Opto- & Microelectronics* (La Jolla, Calif.: Science Applications International Corporation, 1985); and G. Turin and others, *JTECH Panel Report on Telecommunications Technology in Japan* (La Jolla, Calif.: Science Applications International Corporation, 1986).

What may be needed is a set of agreed upon principles of nondiscrimination on the basis of national origin analogous to those ruling trade in conventional goods, as in the GATT. At a minimum, the United States should continue to work for a reciprocal opening of markets in technology-intensive goods that would explicitly strengthen provisions related to government-controlled procurement. Exceptions based on national security considerations should be few and well defined.

Attempts to eliminate subsidies to research and development from international trade in high-tech products—given the compelling economic arguments for, and history of, government involvement in fostering technology development—seem fruitless. A more useful approach might be to open up programs to fund the development of technologies used in internationally traded products, on a reciprocal basis, with the United States' major industrial trade partners. Indeed, bilateral initiatives of this sort have already been discussed publicly. In 1978 some elements in the military and the Department of State favored a bilateral accord permitting Japanese participation in the Defense Department's VHSIC (very high speed integrated circuit) program in exchange for U.S. participation in MITI's VLSI (very large scale integrated circuit) program. Opposition within the Defense Department ultimately killed this exchange, but the proposal demonstrated that serious interest in such accords exists.[27]

Opening up U.S. research programs to industrial competitors on a reciprocal basis would be particularly advantageous in the computer field. All the major industrialized economies are currently funding computer technology programs of comparable sizes. Making the results of these programs available across national boundaries would improve the efficiency of global expenditures on computer research and development by reducing duplication, help others avoid blind alleys, and generally improve the flow of basic, precompetitive information.

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[27] See Jill Hills, "Foreign Policy and Technology: The Japan–US Japan–Britain and Japan–EEC Technology Agreements," *Political Studies*, vol. 31 (June 1983), pp. 212–15.

The Japanese have edged in this direction by seeking international academic participation in their Fifth Generation program, as have the Europeans by accepting IBM and the Digital Equipment Corporation as participants in the Esprit projects of the European Community. In a sense, the United States already has, too, by training in its universities so many of the world's computer scientists. If all current computer support programs in industrialized countries were opened to firms from the other countries active in the field, each country (including the United States) would gain access to research with funding exceeding that of its own national program.

This piecemeal approach toward reducing the impact of any single nation's public R&D support on the competitive position of its firms in international markets seems a useful step toward rationalizing global R&D and improving the potential welfare of all. But the risk of international competition in high-tech products heating up into open trade war, with individual countries closing off their research and markets from competitors, will still exist.

Ultimately, all would lose with such a balkanization of national markets for high-tech goods. Policies designed to slow the international diffusion of technology may well inhibit advance within domestic industry, and by limiting foreign sales reduce the incentive to invest in the development of new technology and the competitiveness of the industries involved. Rather than attempting to erect a fortress around existing national technologies in a futile attempt to preserve some static advantage, international competition could more fruitfully focus on developing new technology as quickly as possible, in order to stay one step ahead in the game.

The most reasonable outcome might be a gradual series of small, partial, and perhaps bilateral steps that liberalize participation in and access to research programs in some equitable fashion. For example, the Japanese government might be asked to permit American firms to participate in its synchrotron research in exchange for entry by Japanese companies into American joint venture research in another high-risk, exploratory area of semiconductor manufacturing technology.[28] The exact outlines of a finished package remain unclear, but it is time to start thinking about what sorts of experiments will lead policy down a productive path.

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[28] The United States retains a lead in key areas of exploratory research on microelectronic manufacturing technology, including ion implantation, thin-film epitaxy,

The challenge for an increasingly technology-intensive American economy will be to steer itself away from the worst, and toward the best, of all possible high-tech worlds. In the worst case—fractious international discord over trade in advanced products—a heavy lid would be slammed over free access to information, U.S. borders would be sealed against the entry of new foreign products, and, overall, use of new technology and the rate of technological progress would slow measurably.

In the best case, international economic rivalry would be channeled into competition based on innovation and differentiation; an ever greater variety of useful products would become available to all people. The greatest fruits from continued growth would then flow to those countries that were best able to nurture innovation and to meet the demands of a wide and sophisticated global marketplace for quality, reliability, and utility. In such a world, basic scientific information would flow freely, international cooperation on fundamental research would be the rule rather than the exception, and competition would focus on the socially beneficial provision of variety and quality.

The choice of futures is America's to make. The only certainty is that the global economy in the next few decades will be tied to technology on a scale never seen before. The development of the computer will perhaps be remembered as the first large step down this road.

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and film deposition and etching. See National Research Council, *State of the Art Reviews: Advanced Processing of Electronic Materials*, pp. 10, 16, 20.

Senator SARBANES. Well, thank you all.

Mr. Flamm, I'd like to ask you where you think the locus of the Federal effort should be with respect to research and development, organizationally? Do you have a view on that?

Mr. FLAMM. Again let me preface my statements by saying that this is my personal opinion, that the council is in the middle of talking about these issues. I think there's a couple of things that are important when you talk about a locus.

First of all, I don't think there should be necessarily a single locus. There are diverse objectives in Federal support for technology. Commercial infrastructure is one of those objectives. Defense objectives are entirely appropriate and different locus. Our social welfare, health research is another locus. I think it would be a mistake to gather all those functions into one organization.

However, I do believe there ought to be a specific organization looking at commercial technology and how the Federal Government can improve investments in the technology infrastructure relevant to industry.

Now as to where within the Federal Government we should locate such an organization, that's a very controversial issue. I would just simply lay out my personal opinion. I think the National Bureau of Standards is a fine organization with a lot of talent. I think the problem of the National Bureau of Standards is that it historically has been part of a very large, diverse organization, the Department of Commerce, which wears many, many, many different hats, and the National Bureau of Standards is only a small player within the vastness that is the Department of Commerce.

Historically, if you look at the history of the National Bureau of Standards, one of the problems that is repeated over and over again, almost cyclically, is the National Bureau of Standards sometimes getting squashed by the Department of Commerce. In the pursuit of other objectives, Commerce tends to give the Bureau short shrift, and in times of budgetary crunches it tends to just slash the budget for the National Bureau of Standards. Also, from time to time a debate on the fundamental issue of the nature of the National Bureau of Standards' mission resumes.

Now at the moment there seems to be a push to move the National Bureau of Standards out front as the main interface between Federal R&D policies aimed at commercial technology and the Federal Government. Historically, that has happened before, and what has resulted is that the National Bureau of Standards has moved out a certain amount in that direction. That tentative thrust has then been chopped off by the top leadership in the Department of Commerce, which often has had different objectives and different feelings about policies that may even have been mandated by the Congress.

Stevenson Wydler is a good example of that sort of thing, and there have been others.

Senator SARBANES. Mr. Saloom, did you have any observations on that question?

Mr. SALOOM. In the Council on Research and Technology, we really haven't addressed where the locus should be. We rather have been formulating our policy and looking at specific substantive areas where we could suggest legislation. Then we can determine where might be the best locus. We are working now—and we want to share with you when we're finished—a few specific things for our future agenda, as was mentioned by the Council on Competitiveness. We need to model and test new methods of technology transfer. We also need to develop and test new commercialization models, rather than just technology transfer—the whole model of commercialization for companies. This should include how you modernize the manufacturing technology associated with commercialization. Further, we are trying to work out what type of seed grants we might suggest for technology partnerships.

When we know what is the function of a point of concentration, then I think it will all probably fall out naturally where the locus should be.

Senator **Sarbanes**. Let me ask the panel this. As you look around the world, who is doing this well?

Mr. **Flamm**. I would be remiss not to at least say the magic word "Japan," when talking about success in moving technology out into commercial products quickly. It has come up in these hearings before.

Mr. **Saloom**. I think we are slower than the Japanese when it comes to commercialization.

Senator **Sarbanes**. Well, if you do it slowly, you lose, don't you?

Mr. **Saloom**. Well, yes, and that may be why we need incentives to accelerate the process. For instance, in 1983, we became very excited in our corporation about the research and development tax credit. We got a tremendous message from our Federal Government that we should be braver and riskier in our R&D undertakings. It was a very important message to us.

The R&D tax credit helped the CEO really discover his research and development department. CORETECH sponsored a seminar in Texas just recently and in the course of talking about encouraging industry/university research relationships, one person said it was going to be a little difficult because management in his own company was just discovering their own research and development laboratory.

I think that the message that can come from this government is that R&D is important. That message will accelerate our efforts. The R&D tax credit certainly did that in my company. It focused our attention on research and development.

Senator **Sarbanes**. What do each of you see as the role of the academic world, the universities, in addressing this situation?

Mr. **Saloom**. Critical, in my mind.

Senator **Sarbanes**. Why is that? I'm inclined to agree with that position, but let me just simply ask why you couldn't have a system where the Government works with the commercial firms to address the question?

Mr. **Saloom**. I don't know whether you can or cannot do that, but I haven't done that with government laboratories. But with industry, when we start to commercialize one product, we often come across technological gaps across a broad range of technologies requiring research that no single company generally can afford, unless they are one of the very major ones. We are talking on the order of $500 million. Most companies cannot afford that.

The universities play a very significant role in "gap technologies." Universities lead us to competence and better understanding and hence swifter commercialization. As a research director, I find the link to universities very vital.

Mr. **Burton**. Can I just add to that? I think that universities and academic research institutions play an extremely critical role. I think that that role will increase if anything. I think one of the trends that we are seeing now with cooperative R&D efforts is an attempt to really break down the barriers between industry and academia and try and draw more on the good work that's being done in the university research facilities that has broader applications.

Senator **Sarbanes**. What's your view of the relevance of defense R&D to this problem?

Mr. **Soloom**. I don't understand the question.

Senator **Sarbanes**. Well, some assert that these charts are misleading in talking about the economic competitiveness issue because there's a large spinoff—or fallout, or whatever term you want to use—from the defense R&D. What's your view of that assertion?

Mr. **Saloom**. CORETECH has really taken no position vis-a-vis one type of research versus another.

I'll answer more individually that they use the same rules, the same DB's, the same volts, and in that sense, it's research. Someone in a broader position than I am can determine its effect on the economy. CORETECH has not taken a position on that.

As a researcher, I follow defense R&D, I use it, I sometimes participate in it, and I don't know sometimes whether I'm doing one or the other.

Mr. **Burton**. The council has taken no position on that issue per se. I think that there is a widely held suspicion that spinoffs for commercial industrial application from defense R&D are less than what they once were. I think that's partly because in many civilian sectors you find technology more advanced now than what is going on in the defense sector. I also think that may stem partly from the fact that defense R&D is overwhelmingly devoted to the "D" side, the development, and basic research comprises a very small part of that budget.

Mr. **Flamm**. If I could just add one comment—again, this is a personal opinion based on my research. There's no question that very important spinoffs come from defense R&D. In the industry I've looked at, the computer industry, it's especially striking.

But the issue is really not the historical importance of the spinoff to particular industries. The issue is the bang per buck ratio, if I can put it that way. We spent enormous amounts of money on these technologies, and for a long period of time, for decades, we were really the only nation spending such enormous amounts of money on this technology. That has changed and our commercial competitors are now spending amounts of money which at least together are approximately similar to the amounts of money that we have been spending.

The question then becomes not so much did this serve us well historically, but are we now getting the kind of commercial return on the dollars that is going to keep us ahead of the new competition?

I think the answer there is, as Mr. Saloom pointed out, that it's the same equipment, it's the same science to some extent, etc. However, there's also the question of objectives. That is, what kinds of projects do you support? What areas do you explore? I think there's a growing interest in the question of whether some of the objectives that are pursued in military-oriented research—you can think immediately if certain kinds of things: radiation hardness, for example, or the ability to cycle very quickly between extremely high and low temperatures—that may be important in a fighter jet but aren't really all that important on the factory floor. A dollar spent on those kinds of objectives really isn't going to buy you much in terms of commercial return. You'll be better off putting your dollar somewhere else if you're interested primarily in commercial return.

There's also another issue. The Defense Department, because it is in a unique position of being the big spender on technology in government, essentially performs a social role by funding programs which are in the long-term interest of the United States as a country, even when those programs may have no direct immediate military impact of significance. For example, the development of timesharing systems on computers in the 1960's or setting up the basic research centers in materials which DARPA undertook in the early 1960's didn't have a real immediate military goal. The problem is that when push comes to shove in the Defense Department—and cyclically these fat years are followed by lean years in the budget—it's the programs that have no immediate relevance to operational systems and immediate defense concerns which get sliced. And historically, there's been this up and down quality to DOD support for more basic, longer term projects without immediate military relevance because, after all, the planners in the Pentagon are mainly concerned about getting what their troops out in the field need to them: in terms of weapons systems, in terms of procurement, etc. And if we rely on the military for our commercial technology, we perhaps are saddling them with a responsibility which is best served by some more focused organization.

So I think it is a serious issue that we ought to consider and look at.

Mr. **Saloom**. You have the nondefense R&D. I think that if we talk about civilian commercial R&D as a subset of that nondefense, then I think you can say, indeed, our nation should encourage and enhance that and funds certainly should be applied there, but that's a big area.

I'm sure that there are many nondefense civilian commercial areas where we could use more R&D at this point.

Senator **Sarbanes**. Do you all regard that chart as significant? Does that tell us anything, or is it irrelevant. Is that important? Is the fact that the United States is where it is, compared to Japan and West Germany, on nondefense R&D as a percent of GNP, something we should be concerned about?

Mr. **Flamm**. I'm not sure whether it's the council's position—but I think the council is concerned about it.

Mr. **Burton**. The council is very concerned about it. We use those numbers often in terms of trying to capture the very elusive measures of how technology relates to U.S. economic competitiveness.

Senator **Sarbanes**. Now suppose someone comes along and says, "I have a chart that shows R&D as a percent of GNP" and drops out the phrase nondefense. Suppose he shows you that chart and says, "Now here's the United States—above Japan and West Germany as R&D as a percent of GNP." What's your response to that person who says we're doing more than they're doing? Of course, this includes all R&D.

Mr. **Burton**. I think that can very appropriately lead you into the question that you just asked. That is, what are the defense spinoffs, spillovers, and contributions to commercialization of innovations and industrial competitiveness?

Senator **Sarbanes**. I take it from your answer that it's not very large, or at least not anywhere near sufficient to offset this. So that to the extent that R&D is an important part of the competition in the civilian sector, the thrust of this chart is that clearly we are lagging behind, we're carrying a, as it were, deficit in that area.

Mr. **Burton**. Yes, I think that's correct.

Senator **Sarbanes**. Well, gentlemen, thank you very much. We appreciate your contribution. The prepared statements will be included in the record.

We will hear our final panel now: Miss Betty Vetter, executive director of the Commission on Professionals in Science and Technology; and Alan Fechter, the executive director of the Office of Scientific and Engineering Personnel, National Research Council. Miss Vetter, why don't you lead off.

STATEMENT OF BETTY M. VETTER, EXECUTIVE DIRECTOR, COMMISSION ON PROFESSIONALS IN SCIENCE AND TECHNOLOGY

Miss **Vetter**. All right. The commission that I represent is concerned with all the manpower issues that are concerning you this morning—the demographic trends among graduate students, the degree recipients, the faculty in science and engineering, including the trends among women and minorities and foreign students, the declining interest in these fields by American students, and the adequacy of current enrollment to meet future U.S. demands.

Although both the number of full-time graduate students in science and engineering and the number of doctorate awards in these fields have stayed fairly constant for the past 15 years, the proportion of all doctorates that are in science and engineering has dropped substantially since the 1950's and 1960's, and I've given you a figure to show you that.

Further, the characteristics of the degree recipients have changed. Today, there are more women, more foreign nationals, even a few more American minorities, among the doctorate recipients than was true 15 years ago.

Some of these changes have been anticipated at the bachelor's level, where in addition to more women and a few more minorities, there have been large shifts among fields within the science and engineering group. Figure 2 in my prepared statement shows you some of those shifts.

The total degree awards in science and engineering are essentially stable since 1950. As a group, science and engineering degrees have been a remarkably steady 29 to 32 percent of all bachelor's degrees awarded since 1953. But we can't count on a steady output of science and engineering bachelor's degrees in coming years for several reasons.

First, women are now earning slightly more than half of all bachelor's and master's degrees in all fields so that their proportion of the total is not likely to continue upward.

Second, the size of the college-age population where most natural science and engineering graduates come from will decline steadily through 1998.

Third, the college-age population is increasingly nonwhite, and minority students have been very poorly represented in science and engineering fields.

Finally, freshmen plans to major in a science or engineering field peaked for both sexes about 3 years ago, and is still declining.

The proportion of women in the freshmen engineering class peaked in 1983 and that proportion has fallen back to 15 percent. Their proportion among computer science graduates dropped from 37 percent in 1984 to a little over 35 percent in 1986.

The proportion of freshmen men and women who plan computer science majors has dropped from 4.5 percent of all freshmen in 1943 to only 1.6 percent in 1986. Only 1.5 percent of 1986 freshmen said their probable career choice was scientific researcher. That's down from 2.2 percent in 1978, of a much larger class.

Women's share of science and engineering bachelor's degrees has been a steady 32 percent for the past 4 years. But they have earned at least half of all the bachelor's degrees since 1981. As figure 3 in my prepared statement shows you, their representation among physical science graduates never went above 28 percent. It has dropped back to 27 percent in 1986.

Only in the life, social, and behavioral sciences did women attain or even come near their proportional half of bachelor's degrees in any science or engineering field.

The non-Asian U.S. minorities achieved even less entry into science and engineering professions over the decade. Among bachelor's graduates in science, blacks have dropped from 6.4 percent of the class of 1979 to 5.6 percent of the class of 1985. Hispanics earned 3.3 percent of the science bachelor's degrees in 1979, 2.7 percent in 1985. In engineering, where a very concentrated and fairly costly effort has been made to increase minority participation, blacks make up only 2.7 percent of the 1986 bachelor's graduates; Hispanics only 2.4 percent; and American Indians less than 0.2 of 1 percent.

The data at the bachelor's level are discouraging, but at the Ph.D. level I think they are dismal. The steady state of doctorate awards in science and engineering has held only because of the increasing numbers of foreign students and women earning these degrees.

In 1975, 13,800 American citizens earned doctorates in some field of science and engineering; 18 percent of them were women. By

1985, that number had dropped to 12,900, 32 percent were women. As you see in figure 4 in my prepared statement, the 68-percent increase in doctorate degrees earned by American women has not made up for the 23-percent drop in the number earned by white American men.

So by 1986, U.S. citizens earned only 67 percent of all Ph.D. awards from American universities in all of the sciences and engineering.

Efforts to increase graduate participation of U.S. minorities show mixed results. As you can see in figure 6 in my prepared statement, science and engineering doctorate awards have risen slightly for Hispanics, American Indians and American Asians. There's been a decline in doctorate awards to black Americans over the decade.

In the combined fields of engineering, mathematics, physical and computer sciences, foreign students earned six times as many doctorates in 1975 as did all American women and all American minorities combined. By 1985, they earned four times as many.

Does that indicate we're educating too many foreign students in our graduate schools? A lot of people think so, but I am not one of them. The real problem is that we need more American students, both sexes, all racial and ethnic groups, rather than fewer foreign students.

Although U.S. education of foreign students does represent a substantial cost to American taxpayers, these individuals both as students and as additions to our own science and engineering labor force also make large contributions to American research, particularly at the university level.

About two-fifths of foreign graduates in technical fields at the doctorate level return to their home countries. The remainder fill U.S. needs for researchers and faculty which cannot be filled by American graduates. If foreign students and faculty were suddenly all withdrawn from U.S. universities, the research and teaching activity of many university departments would totally collapse.

In order to protect jobs for U.S. citizens, the Congress has required the Labor Department to impose a series of onerous, expensive, time-consuming steps to be taken by any employer desiring to hire a foreign graduate who's here on a temporary visa. The fact that so many are hired and stay here, in spite of this burden indicates our need for their services. The unemployment level among U.S. doctorate science and engineers, particularly in the fields of engineering, math, and physics, where foreign students predominate, is less than 1 percent.

We have no current shortage of bachelor's and master's level graduates in science and engineering, but few foreign graduates at these levels remain in the United States except as graduate students.

Although I have seen no evidence that qualified American graduates have been denied admission to U.S. graduate schools because of the admission of foreign students, there is a question as to whether many of the best American students bypass graduate school because of the significant drop in direct Federal support for graduate study. This has occurred over the past two and a half decades and you can see it in figure 8 in my prepared statement.

Indirect support is provided to students through federally funded research grants, but we don't know the relative amount of that support that is spent to support U.S. versus foreign students who are serving as research assistants.

As you can see in figures 6 and 7 in my prepared statement, university support is the major form of support for both groups and that support includes both teaching assistantships and research assistantships. Some of that money comes from the Federal Government. But twice as high a proportion of Americans as of foreign students who have earned science and engineering doctorates over the past decade report self-support and loans as their primary source of support for graduate study.

Further, women are almost 1½ times as likely as men to have to rely on self-support and loans to get through. We may be supporting foreign graduate students at the expense of American graduate students.

The final question is whether we will have enough scientists and engineers to meet our foreseeable needs for the next decade and the answer is very uncertain. There are already areas for which we would not have enough qualified graduates without utilizing our foreign graduates. These include faculty positions in engineering, computer science, and increasingly in physics. Nonetheless, assuming that we do not force all foreign graduates to leave the country after completing their doctorates, it's unlikely that we will have so few scientists and engineers that major funded projects will be scrapped or even seriously delayed by a lack of technological personnel. As we've always done when we needed more professionals in these fields, we will entice them in from peripheral fields. We will bring back those who left these fields the last time funding and therefore jobs dried up. We will encourage these transfers by raising salaries, perhaps softening the immigration requirements to allow more of our foreign graduates to stay here.

But this doesn't mean we will have the best we could have. Only if we utilize a wider segment of the Nation's talent pool, including its women and its increasing proportion of minorities, can we get the best that we could have. If we don't do more to encourage and assist women and minority students to prepare for careers in science and in engineering, we almost certainly will fail to produce enough good U.S. graduates to meet our needs. And that will take some changes.

Both an increase in support for American graduate students and some indication by the Congress that jobs will be available for those who pursue graduate study may be required. The uncertainty about future U.S. budgets for activities that require significant numbers of scientists and engineers is a deterrent to embarking on a 7- to 10-year program of graduate study. Our future requirements for scientists and engineers are not dependent on how many we need to maintain technological leadership; they are dependent on how many can be hired because positions are funded.

It's largely the Congress that determines where research money is allocated and thus where job openings occur. So I think it's terribly important that Congress consider together the needs for support for graduate education and the needs for technological advancement.

Thanks for the opportunity to express these concerns.

[The prepared statement of Miss Vetter follows:]

PREPARED STATEMENT OF BETTY M. VETTER

I want to examine briefly all of the issues you are concerned with this morning - the demographic trends among graduate students; degree recipients and faculty in science and engineering, including trends among women, minorities and foreign students; the declining interest in these fields by U.S. citizens; and the adequacy of current enrollments to meet future U.S. demand. All are deep concerns of the Commission that I represent.

The number of full time graduate students in science and engineering, and particularly in the natural sciences, has remained essentially constant over the past 15 years. Doctoral awards in these fields also have stayed approximately level, although science and engineering PhD degrees have dropped as a proportion of all Ph.D.s awarded, compared with the 1950s and 1960s (figure 1). Internally, within the science and engineering fields, large changes have taken place. They include a significant increase in the number of degree recipients who are women; an equally significant decrease in the number who are American men; and a large increase in those who are foreign students on temporary visas.

At the bachelor's level, there have been large shifts among fields within the science and engineering group, but the total number of degree awards in science and engineering fields has not changed much since 1970, and the proportion of all bachelor's degrees that are awarded in science and engineering fields is remarkably steady at 29-32 percent from 1953 through 1986 (figure 2). Over the past decade, the total has been made up of increasing numbers of women and decreasing numbers of men earning degrees in these fields. However, we cannot count on a steady output of degrees at the bachelor's level in coming years for several reasons.

First, women are now earning slightly more than half of all bachelor's and master's degrees, so that their proportion of the total is not likely to continue upward. Second, the size of the college age population - a group that typically produces the vast majority of all natural science and engineering majors, will decline steadily through 1998. Finally, freshman plans to major in a science or engineering field peaked for both sexes about three years ago, and the decline in interest in these fields is beginning to show up at the baccalaureate level.

For example, as a proportion of first year engineering students, women increased from 2% in 1970 to 17% in 1983, or an average 1.1 percentage points per year for 13 years. However, in fall 1984, the proportion of women in the freshman class dropped back to 16.5%, where it held for the fall 1985 freshmen, before dropping to 15.4% of the fall 1986 freshman class.

Women's share of bachelor's degrees in computer science rose from 13.6% in 1972 to 37.1% in 1984. However, by 1986, the proportion had dropped back for two years to 35.7%. The 1985 peak of 27.5% of bachelor's degrees in the physical sciences dropped to 27.4% in 1986. Only in the life, social and behavioral sciences did women attain or come near to their proportional half of baccalaureate graduates in the science and engineering fields. Their proportionate representation now appears to have peaked in each of these fields, and has been a stable 32 percent of all science and engineering bachelor'sa degrees for the past four years (figure 3).

Non-Asian U.S. minorities have achieved even less entry into science and engineering professions over the past decade. Among bachelor's graduates in science, blacks have dropped from 6.4% of the class of 1979 to 5.6% of the class of 1985. Hispanics earned 3.3% of science bachelor's degrees in 1979 and 2.7% in 1985.

Data at the bachelor's level are discouraging. At the Ph.D. level, the U.S. data are dismal. The steady state of doctoral awards in science and engineering has held only because of increasing numbers of foreign citizens and women earning these degrees. In 1975, 13,853 American citizens earned doctorates in some field of science or engineering, and 18 percent were earned by women. By 1985, that number had dropped to 12,940, and 32 percent were awarded to women. While the number of doctorates in science and engineering earned by American women increased by 68 percent over the decade, the number earned by American men dropped almost 23 percent, and the drop occurred in every field except the life sciences. The increase in the number of American white women did not make up for the decrease in American white men (figure 4). Thus, by 1986, U.S. citizens earned only 67% of all PhD awards from American universities in the sciences and engineering.

Efforts to increase participation of U.S. minorities have had mixed results. In the combined science/engineering fields, the number of doctoral awards to non-Asian minorities has increased slightly over the decade, but the increase is largely in the social and life sciences and the numbers are small. There has been an actual decline in doctoral awards to black Americans over the decade (figure 5). In the combined fields of engineering, physical, mathematical and computer sciences, blacks earned 52 PhDs in 1975, but only 49 in 1985. Hispanics earned 42 such degrees in 1975 and 58 a decade later. American women earned 309 in 1975 and 607 in 1985. Meantime, foreign nationals earned 2,742 doctorates in these fields in 1975 and 3,526 in 1985. Even adding in the few American Indians and the relatively large number of Asian American recipients, foreign students earned six times as many doctorates in these fields in 1975 as did American women and all American minorities combined; and four times as many in 1985.

Does that indicate that we are educating too many foreign students in American graduate schools? Although many individuals think that is the case, I am not one of them. We need more American students - both sexes and all racial/ethnic groups, rather than fewer foreign students.

There are many legitimate reasons to question the wisdom of educating so many foreign students at the expense of the American taxpayer - and it is an expense to us. Tuition pays less than half of the cost of graduate education - probably considerably less in science and engineering where equipment costs are very high. Foreign governments pay an insignificant share of the cost of educating the students from their countries. Foreign graduate students are supported principally by teaching assistantships and research assistantships, just as American graduate students are (figures 6 and 7).

The language barrier for many foreign students makes their service as teaching assistants a questionable practice. Further, because of their cultural backgrounds, they often view women in ways that are inappropriate in the U.S. and may discourage or turn away American women students who must work with foreign teaching assistants and/or faculty members. This is particularly troublesome in engineering, in computer science, and in physics, where foreign citizens are a large and increasing proportion of graduate students and of recent faculty hires.

About two fifths of foreign graduates in technical fields return to their home countries, taking with them the technical knowledge acquired in U.S. universities. The rest become a part of the U.S. science and engineering labor force, resulting in a brain drain from their home countries.

That is the negative side. On the other hand, foreign students provide their knowledge and talent to American research in the universities where they serve, first as research assistants, and later as low-paid postdoctoral researchers, and finally, in many instances, as faculty members. If foreign students and faculty were suddenly all withdrawn from U.S. universities, the research and teaching activities in many university departments would collapse.

The approximately 60% of foreign science and engineering graduates who stay in the U.S. become a part of the immigrant base that has provided talent to U.S. science throughout its history, and which includes such immigrants as Einstein, Fermi, Von Braun, and Wang. They have enriched the nation. Further, the foreign graduates in science and engineering who stay in the U.S. are far more likely than the handful of U.S. graduates to remain in the university system as faculty researchers - earning less than they might in industry. Perhaps most universities, if they had a choice of equally qualified U.S. and foreign applicants for faculty positions in science and engineering, would choose to hire Americans. But they do not have that choice, because too few Americans are earning doctoral degrees in these fields to fill the open positions in industry, government, and academe.

Foreign graduates who return home bring back to their countries (who are our trading partners) new skills and knowledge, thus repaying some of the brain drain of those who choose to and are able to stay here.

Congress has been ambivalent about the utilization of foreign students and graduates, and has considered and rejected legislation forcing them to return home (or at least leave the U.S.) for periods of time after completion of their study. However, in the name of protecting jobs for U.S. citizens, the Congress has required the Labor Department to impose a series of onerous, expensive and time-consuming steps to be taken by any employer desiring to hire such graduates. The fact that so many are hired and do remain in the U.S. despite this burden indicates the need for their services. However the new immigration law caps the number of years that foreign citizens may continue to work here on temporary appointments, even after being certified as essential employees, as if American workers with similar qualifications were suddenly going to be available.

America has always relied on the extra energy and drive that immigrants bring with them. The fact that American students are not choosing to enter science and engineering fields in growing numbers, or to pursue a long and arduous doctorate, makes it imperative that we utilize those in whom we have invested training and money, when they wish to stay. Brainpower is a precious comodity, without which we cannot continue to hold a position of leadership in an increasingly technological world.

The fact that the best and brightest students from other countries want to study in our universities indicates the high quality of U.S. technological education. The large fraction of foreign technical graduates who remain in the U.S. increases the quality of our science and engineering work force. A decision to make these choices less available to foreign students and graduates, by capping foreign enrollments, charging significantly higher tuition to foreign students, or prohibiting their employment here after completion of their education, would reduce our opportunity both to improve our own science and engineering capabilities and to maintain the high quality of our universities and university research.

We have no current shortage of bachelor's level or master's level scientists or engineers, and few foreign graduates at these levels remain in the U.S. except as graduate students. But we are not producing a sufficient number of U.S. Ph.D.s in several of these fields to meet our needs for faculty and researchers.

Despite complaints by some groups that foreign graduates remaining in the U.S. take jobs from Americans by working for lower salaries, studies show that foreign Ph.D.s who stay here and become a part of our workforce are paid at the same levels as Americans in similar jobs. The unemployment level among U.S. doctoral scientists and engineers, particularly in fields where foreign graduates predominate, including engineering and some of the physical and mathematical sciences, is well below one percent.

I have seen no evidence that qualified American graduates have been denied admission to U.S. graduate schools because of the admission of foreign students. There is, however, a question as to whether many of the best American students bypass graduate school because of the significant drop in direct federal support for graduate study that has occurred over the past two and a half decades (figure 8). We do not know the amount of indirect support provided to graduate students through federally funded research grants, nor do we know the relative amount of that support that goes to U.S. vs. foreign students. What we do know is that "university" support in the form of research and teaching assistantships predominates as a support source for both American and foreign science and engineering graduate students, and much of the funding for research assistants comes from federal grants and contracts.

As you will note in figures 6 and 7, twice as high a proportion of American as of foreign students who have earned science and engineering doctorates over the past decade report self support and loans as their primary source of support for graduate study. Further, even among U.S. citizens, women are much more likely than men to have to rely on self support and loans to complete a graduate degree in science or engineering. Probably more federal help for American graduate students would increase American enrollment in these fields.

The final question is whether we are enrolling enough students in science and engineering, and educating them sufficiently to meet our foreseeable needs over the next decade or so. The answer is uncertain. There are already areas for which we would not have enough qualified graduates without utilizing our foreign graduates, including faculty positions in engineering, computer science, and increasingly physics. In general, assuming that we do not force all foreign graduates to leave the country after completing their doctorates, it is unlikely that we will have so few scientists and engineers that major funded projects will be scrapped, or even seriously delayed, by a lack of technological personnel.

As we have always done when we needed more professionals in these areas, we will entice them in from peripheral fields, bring back those who left these fields the last time funding (and therefore jobs) dried up, and encourage inter-field or inter-sector transfers by raising salaries, and perhaps softening immigration requirements to allow more of our foreign graduates to stay here.

But this does not mean that we will have the best we could have. The number of Americans of typical student age is declining, and at the same time, this group is increasingly non-white. Only if we utilize a wider segment of the nation's talent pool, including its women, can we get the best we could have. If we do not do more to encourage and assist women and minority males to prepare for careers in science and engineering, we almost certainly will fail to produce enough good new graduates to meet our needs. And that will take some changes. The available data indicate that without further encouragement, American students of both sexes and all racial/ethnic groups will continue to decrease their participation in science and engineering.

To avoid or lessen further decrease, both an increase in support for American graduate students in these fields, and some indication by the Congress that jobs will be available for those who pursue graduate study when they have completed their training may be required. The uncertainty about future U.S. budgets for activities that require significant numbers of scientists and engineers is a deterrent to embarking on a long program of graduate study.

Our future requirements for scientists and engineers are not dependent on how many we need to maintain technological leadership, but on how many can be hired because positions are funded. It is largely the Congress that will determine where money is allocated, and thus, where job openings will occur. It is therefore important to consider together the needs for support for graduate education and the needs for technological advancement.

Thank you for the opportunity to express these concerns.

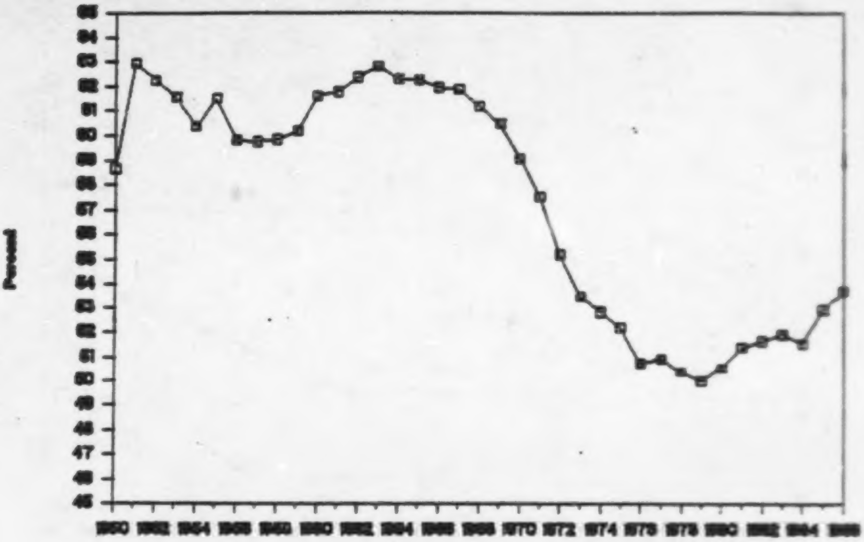

figure 1. Science and engineering doctorates as a percent of all Ph.D. awards, 1950-1986 [Data source: Center for Education Statistics]

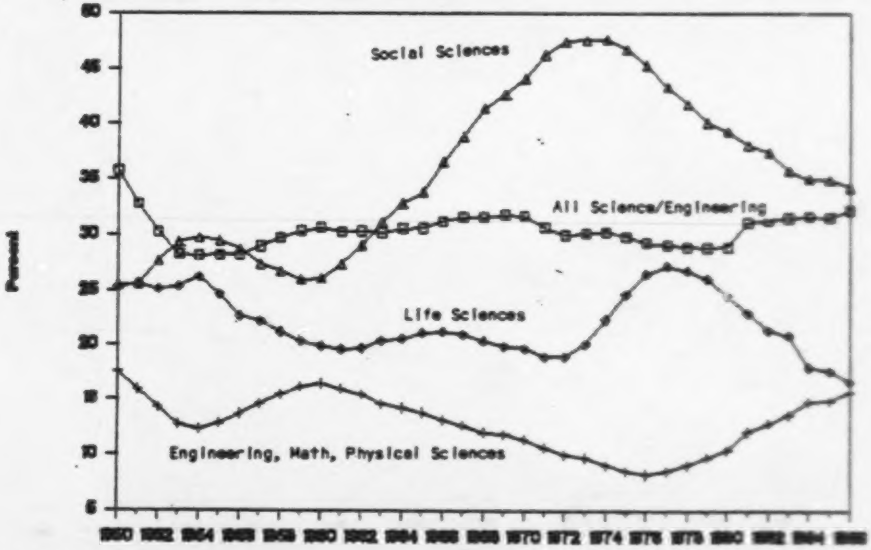

figure 2. Science and engineering degrees as a percent of all Bachelor's degree awards, 1950-1986 [Data Source: Center for Education Statistics]

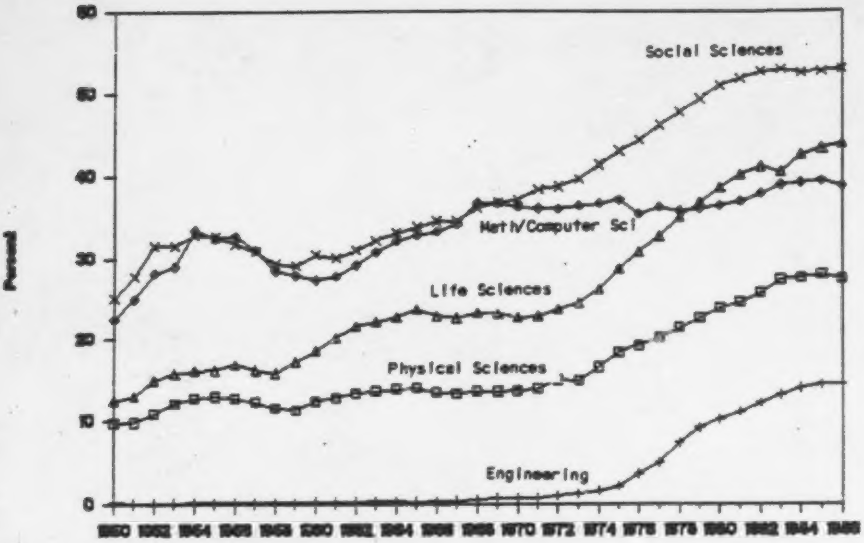

figure 3. Percent of science and engineering bachelor's degrees earned by women, 1950-1986 [Data source: Center for Education Statistics]

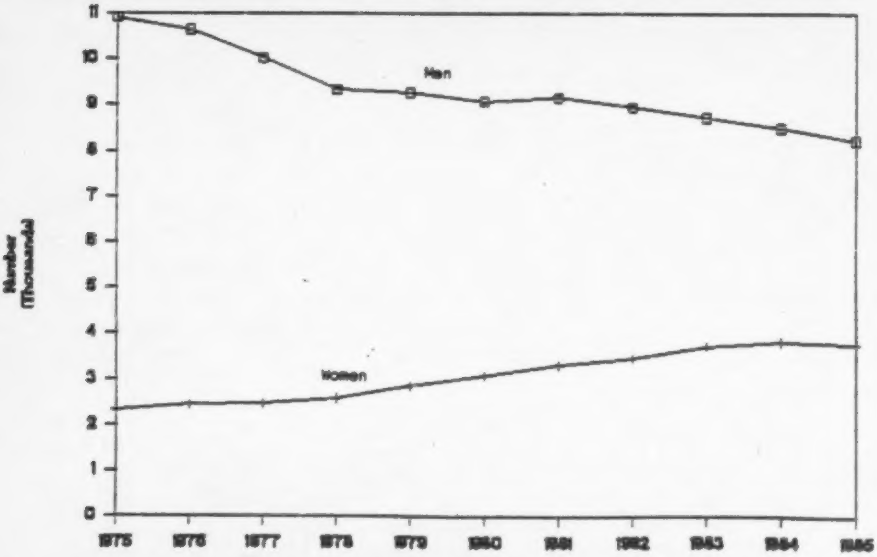

figure 4. Number of science and engineering doctorates earned by U.S. white, non-Hispanic citizens, by sex, 1975-1985 [Data Source: National Research Council Doctorate Records File]

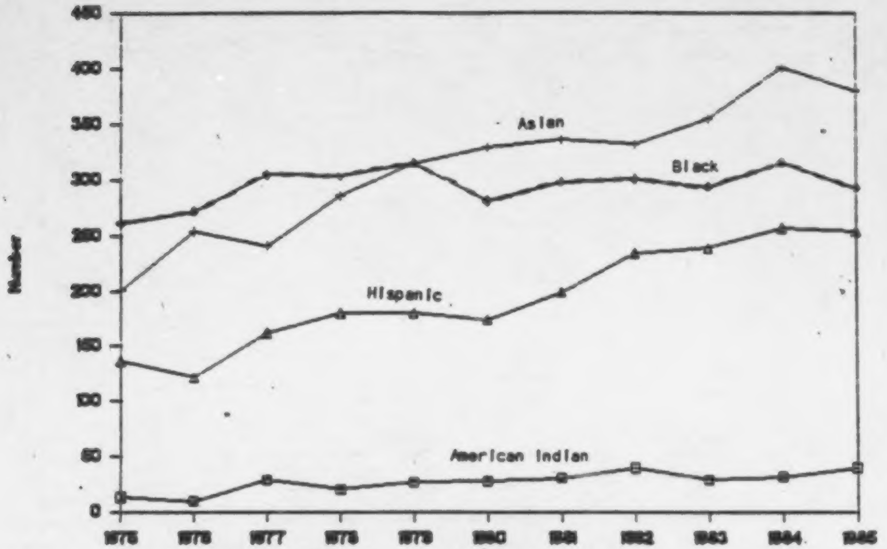

figure 5. Number of science and engineering Ph.D. degrees earned by U.S. racial/ethnic minorities, 1975-1985 [Data source: National Research Council Doctorate Records File]

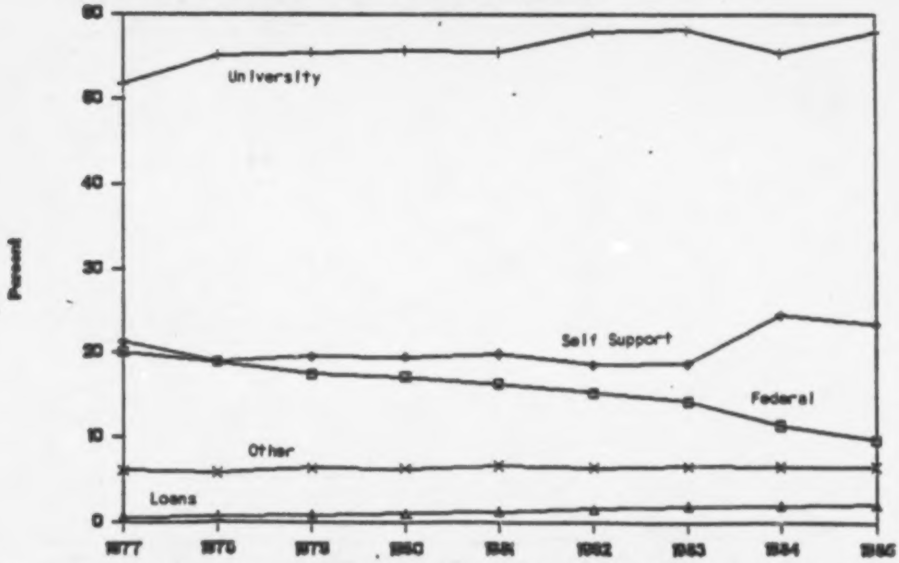

figure 6. Primary source of support during graduate school of science and engineering doctorate recipients, 1977-1985 [Data Source: National Research Council Doctorate Records File]

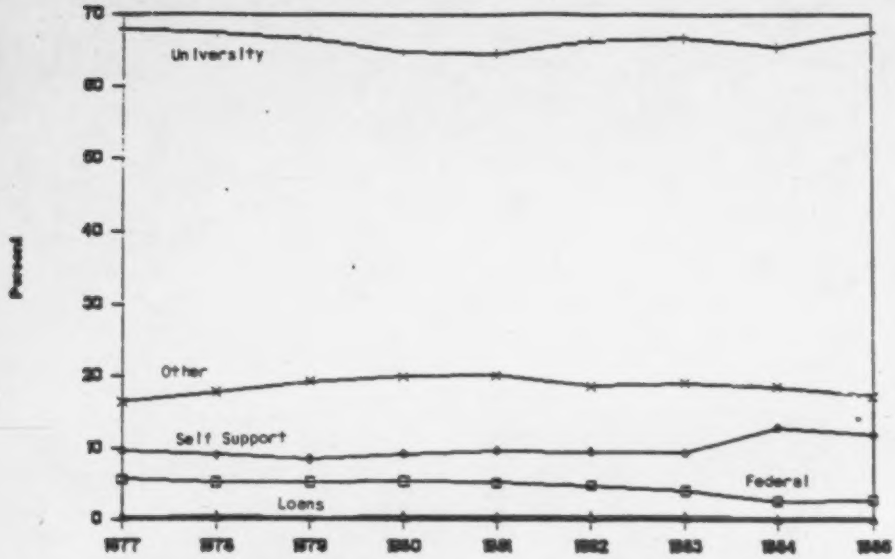

figure 7. Primary source of support during graduate school of foreign recipients of U.S. science and engineering Ph.D.s, 1975-1985 [Data source: National Research Council Doctorate Records File]

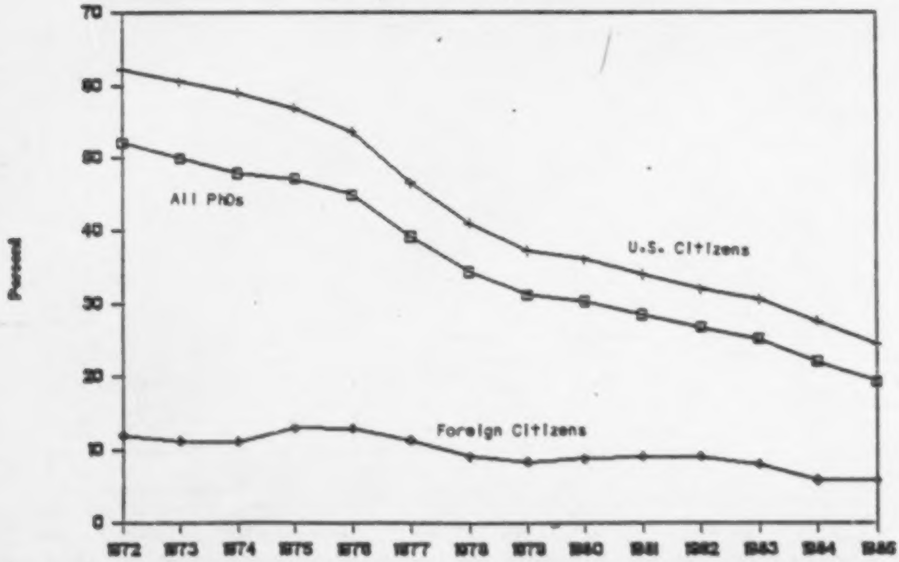

figure 8. Percent of science and engineering doctorate recipients with direct federal support for graduate study, by citizenship, 1972-1985 [Data Source: National Research Council Doctorate Records File]

Senator **Sarbanes**. Well, thank you very much for a very helpful statement.

Mr. Fechter, why don't we hear from you now.

STATEMENT OF ALAN FECHTER, EXECUTIVE DIRECTOR, OFFICE OF SCIENTIFIC AND ENGINEERING PERSONNEL, NATIONAL RESEARCH COUNCIL

Mr. **Fechter**. Thank you, Mr. Chairman. In the interest of controlling a chronic affliction toward long-windedness, I am going to read my prepared statement in the interest of time. It is slightly amended from the prepared statement I sent over, so those of you who have copies will notice there will be some slight difference in treatment.

I am delighted to be able to appear before your committee to present my views on this very important subject. Although I am employed by the National Research Council, I wish to emphasize at the outset that the views provided in this statement do not necessarily represent the views of the National Research Council, the National Academy of Science, the National Academy of Engineering, or the Institute of Medicine, all part of the academy complex from which I come.

Your letter of invitation indicated interest in a number of significant issues: demographic trends of graduate students, graduate-degree recipients, and teachers in science and engineering fields; the reasons for the apparent lack of interest among American students in pursuing careers in these fields; the adequacy of current enrollments to meet future national needs in these fields; and the proper role of Federal policy in dealing with these issues. These issues are being raised in the larger context of Federal research and development policy.

In my remarks I shall only briefly review the issue of demographic trends, since my colleague, Betty Vetter, has treated it much more knowledgeably and eloquently than I could. Then I shall focus my attention on other issues, although I must say, having heard Betty's statement that there is a great deal of agreement between us.

Let me start with demographic patterns. The broad pattern of trends is familiar to most of us who toiled in the human resource vineyard. The number of doctorates granted in science and engineering fields has recently begun to increase after an extended period of decline. The increase can be attributed entirely to growth in the number of degrees granted to foreign students and to women. The number of white males earning doctorates has been declining steadily and the number of minorities earning doctorates has been struggling to remain level. I could have simply taken Betty's statement and simply given it for the record.

But the numbers only tell part of the story. Prominent members of the scientific community have expressed concern that, regardless of field, the most able academic students are no longer opting for research careers.

We also miss an important part of the story, if we confine ourselves only to the doctorates. Most of our technology comes from the efforts of engineers and, more recently, from computer specialists—fields in which holders of the bachelor's degree predominate. The number of bachelor's degrees has been growing dramatically in both of these fields. However, as Betty mentioned earlier, evidence of shifts in the career intentions of freshmen suggests that degree production may peak this year in these fields and will begin to decline until at least the end of this decade.

Another element of the demographic story is the relative underrepresentation of women and members of racial and ethnic minority groups among these degree recipients—at the level of both the doctorate and the bachelor's degree. Women currently receive about one-fourth of the doctorates granted in science and engineering fields and about two-fifths of the bachelor's degrees granted in these fields. They constitute an even smaller share of the degrees granted in what I call the "quantitatively oriented" fields—for example, engineering, physical sciences, and mathematics. Among minority groups, Hispanics currently earn less than 5 percent of bachelor's degrees and 2 percent of the doctorates awarded in these three fields, and Native Americans earn less than 1 percent of both of these degrees. For blacks, the underrepresentation is most pronounced in the quantitative fields. In 1986, 24 blacks earned doctorates in engineering, 8 blacks earned doctorates in physics, and 6 blacks earned doctorates in mathematics. I think that's a dramatic statistic.

Offsetting these grim statistics for women, blacks, Hispanics, and Native Americans, a relatively large number of Asians earn degrees in these fields, and their degrees are particularly concentrated in the quantitative fields. Parenthetically, I might add that an interesting research question has to do with why the Asian Americans gravitate to these fields, whereas the other minority groups don't. We might learn some interesting lessons from such a study. Many people think it's a matter of values. Others say it is social class. I think we need to look into that question much more closely.

Senator **Sarbanes**. Do you have a view on that?

Mr. **Fechter**. I think it's a combination of both, although I think values are probably the more important factor in this case. The behavior of Asian Americans reflects the combination of two things: the goal of social advancement that is common to most second generation ethnic groups and the value that particular ethnic groups place on achievement that will come from advancement in scholarly careers in these areas. It's remarkably similar to what we saw back in the 1920's and 1930's with other ethnic groups—Jews, Italians, who are now as a matter of fact coming in our research community in large numbers. Amongst American Asians, the pattern seems to be more like the pattern that we saw in the behavior of earlier minorities. So I think the value system is very important.

Senator **Sarbanes**. Well, conceding that the value system places a premium on learning and education, why does it lead into the science and engineering fields?

Mr. **Fechter**. I can only give you speculation on this issue. Language difficulties in this case may be a part of it. The language of mathematics is universal; then disciplines requiring facility in other languages aren't so popular. That may be an important factor.

Let me now turn to whether interest has declined amongst American students. Do these statistics indicate a relative decline in interest in science and engineering careers? If so, what are the possible reasons for this decline? The answer to the first question appears to be a resounding "yes"—at least for the period of time when degree production was falling. The declines occurred at a time when the statistical indicators of the pool from which these degree recipients could be drawn—the 22-year-old and the 30-year-old populations—were rising.

Possible reasons for this apparent decline in interest center on incentives—the monetary and nonmonetary benefits to pursuit of such careers relative to the cost of acquiring the necessary training. Simply put, many believe that students do not perceive such training to be a profitable way to invest their scarce time and family resources.

One consequence of the buildup that occurred in the 1960's in R&D and graduate-level training activity was a saturation of the academic market so that in recent years, job opportunities for new doctorates have been meager. Betty Vetters' testimony earlier reinforced that position.

Moreover, even if a new doctorate was able to acquire an academic position in a reasonably prestigious institution, the security of that position would depend critically on the ability to acquire funding, typically from Federal sources, for his or her research activity. Federal funding of R&D activity fell steadily in the early to mid-1970's—the period during which degree production in most science and engineering fields began to fall from their earlier peaks. Although Federal funding for R&D has grown dramatically in recent years, much of it has been oriented to defense activity and, in the current Gramm-Rudman-Hollings environment, all Federal sources of funds have been subject to a considerable amount of uncertainty.

It now takes approximately 8 years for the average student to complete a Ph.D. in science or engineering, and this number has been rising steadily since 1970. Given the poor state of conditions in academic labor markets, the primary employer of these Ph.D.'s, the relatively low salaries that are paid in that sector of the economy, the declining trends in Federal R&D funding of the early 1970's, and the uncertainties with respect to Federal funding that exist today, it is not unreasonable to surmise that students perceived this to be a poor investment of their time.

Will the current rate of degree production be adequate to meet future national needs? This issue is clouded by a considerable amount of uncertainty.

On the supply side of the market, the demographic situation is clear. The pool from which degree recipients will be drawn is already declining and will continue to decline into the 1990's. It is also clear that there will be a substantially larger need to fill job openings created by the retirement of the generation of researchers spawned in the halcyon days of the 1960's. In addition, it can plausibly be argued that the increasingly technological complexity of our society and the growing value of this technology in maintaining our industrial competitiveness in an increasingly global economy will give rise to the need for more scientists and engineers in the years ahead.

What is not clear is whether, in the absence of government actions, these needs will produce changes in the market—for example, salary increases, increases in the number of job opportunities—that will induce an adequate number of additional students to consider careers in science and engineering. Even if they do, a question remains as to whether these changes will operate on student choices rapidly enough. If students' choices are based on conditions that exist at the time of their decision, and if these decisions are made at least 7 to 8 years before the ultimate receipt of the degree, then it is possible that there will be problems if production rates do not increase above current levels. Recent data indicate that these rates may be starting to increase, but it is not at all clear that these increases will be sustained.

Given these uncertainties, decision theory suggests that policy be formulated on the basis of minimizing the costs of a wrong decision. In this particular case, the tradeoff is between (1) acting as if the problem will be solved by the normal operation of market forces and being wrong and (2) acting as if the market will produce an inadequate response and being wrong.

Clearly, a wise policy decision would be to invest resources in reducing the range of uncertainty that exists about these issues and in disseminating the information about future market conditions widely. In the absence of better information about the future, it would also be prudent to adopt policies that will facilitate coping with any stringency that may arise from the adverse demographic trends.

I believe that such coping will require us to consider a variety of alternative mechanisms: (1) policies that will increase the available supply—such as reduction of barriers to employment of foreign scientists and engineers, increased financial support to graduate students—either through fellowships and scholarships or through R&D projects—and encouragement of women and members of underrepresented minority groups to pursue careers in these fields; (2) policies that will use the existing supply of scientists and engineers more effectively—such as more systematic use of midcareer training or new equipment or technologies—for example, automated data processing equipment. In addition, Federal policy can aim at reducing the degree of uncertainty and cost that is associated with the Federal R&D process itself. This uncertainty can be reduced in a variety of ways—by reducing year-to-year variability in R&D funding—including the funding of fellowships—by funding projects over longer periods of time—for example, by appropriating multiyear R&D budgets rather than going year by year—and finally, and not least, by simplifying the grant-application process that we now confront.

If we are judicious in how we proceed through these uncharted waters, I believe we will be able to bring the science and engineering vessel safely to port.

This concludes my testimony, Mr. Chairman. I would be happy to answer any questions.

Senator **Sarbanes**. Well, as sometimes happens around here, all these bells and lights and beepers mean that there's a vote, and apparently there's going to be a series of votes. So I think what I'd better do is thank you very much for your testimony. We may submit some written questions to you, but we very much appreciate the contribution you have made to our examination of this issue. I apologize for the fact that the pressures of the Senate are such that we are not going to be able to have a questions session here this morning.

Thank you all very much.

The committee stands adjourned.

[Whereupon, at 11:45 a.m., the committee adjourned, subject to the call of the Chair.]

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